Journal of Experimental Psychology

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REACTION TIME TO KINESTHETIC STIMULATION RESULTING FROM SUDDEN ARM DISPLACEMENT [1]

RUBE CHERNIKOFF AND FRANKLIN V. TAYLOR [2]

Naval Research Laboratory

The suggestion has been made (**2, 3, 4, 10**) that man's control of precise hand and arm movements is analogous to the operation of a servo system. The response of a continuously-following servo involves the comparison, at all times, between the input and the output with the discrepancy between the two utilized as the basis of control. If man acted as a continuously-following servo motor his responses would be guided continually by the degree to which the intended motion had not yet been made.

Such a mode of control would require that continuous information be furnished concerning where the body member is and where it should be. The position of the hand or arm in space might be derived from visual or kinesthetic stimulation (or feedback, as it is called by engineers). Information regarding the intended terminus of the movement would in most instances be furnished by vision, though movements made with closed eyes would seem to require that this information be supplied by imagery of one kind or another.

As a partial test of this servo hypothesis, Taylor and Birmingham (**8**) conducted an experiment to investigate the effect of disrupting the visual feedback on the control of quick manual corrective responses. The *S* was presented with a visual target which jumped quickly to the right or to the left and which could be moved back to a center line through the use of a joystick. After making a number of quick correction responses, the equipment was set so that *S* suddenly found that he had lost all control of the target and could not return it to center. In spite of this, the force pattern of his now futile response was indistinguishable from what it had been in the normal situation where he could see the target returning to center as he moved the joystick. In another experiment, conditions were arranged so that on certain test trials *S*'s normal corrective movement re-

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sulted in a movement of the target in the reverse direction, away from the center line. This also produced no modification in the initial correction motion though a second movement in the opposite direction was finally made to center the target.

These studies led the authors to conclude that once a quick response was started, it ran its whole course unmodified by visual information arising during the response. This conclusion is in harmony with what is known concerning visual reaction time, for it is difficult to see how a movement under way could be modified in less than one reaction time by visual events produced by the response. The duration of the movements employed in the above study was approximately the same as that of the reaction time, with the result that no visually induced modification in the response could be expected to occur unless the reaction time was decreased in some way. The study showed no evidence of any such shortening of reaction time.

Similarly, it can be argued that if the kinesthetic reaction time is of the same order as the reaction time to a visual stimulus, kinesthetic information concerning the course of a movement could have no effect on short-duration responses. The present study was undertaken to determine the length of the kinesthetic reaction time.

Only two other attempts to make this determination have been found in the literature. Both of these (**5, 9**) were studies directed toward discovering the minimum length of time required for *S* to amend a response in reply to a sudden increase in resistance to a hand motion. The two experiments resulted in widely discrepant values; one giving a reaction time of 160 msec., the other 300 msec. This marked difference in results, together with the compounding of variables which a study of both experiments discloses, makes a further measurement of kinesthetic reaction time essential.

The kinesthetic stimulus in the present experiment was provided by dropping *S*'s splinted right arm, which at the start was held in position by an electromagnet. Although the stimulus is referred to as kinesthetic, it should be understood that there is a tactual component included, since the dropping of the arm results in a change in pressure of the splints against the hand and arm. For purposes of comparison, reaction times to auditory and tactual stimuli were also determined. For these, the conventional method of indicating the response by the release of a telegraph key was used. In the kinesthetic reaction time condition, it was possible to have *S* indicate his response by stopping his falling arm and measuring the onset of the change in the acceleration of the arm as he was accomplishing this act. In order to have a direct comparison with the other modalities, the key-release response to the kinesthetic stimulus was also included.

Apparatus

The *S*'s presentation equipment was located in a room separate from that containing the control and recording equipment. A two-way speaker system was provided for communication between the two rooms.

Kinesthetic reaction time.—An electromagnet was mounted on an extension bracket which attached to a wall so that when *S* sat on a stool facing the wall his outstretched right arm, encased in splints, was parallel to the floor and held up by the magnetic attraction between a soft-iron bar fastened to the top splint and the poles of the magnet. Pieces of $\frac{1}{16}$ in. lucite were cemented to the bottom of the magnet poles. The soft-iron bar which made contact with the lucite was triangular in shape, with its vertex smoothly rounded and polished. This arrange-

ment provided surfaces which separated noiselessly when the magnet current was broken.

Splints were used to keep the arm from bending at the wrist and elbow. (Without splints, accelerations produced by the bending of the wrist and elbow, when combined with the downward fall of the arm, would have made the records difficult to read and interpret.) The splints were made of $\frac{1}{16}$-in. aluminum, 2 in. wide and 24 in. long. They were ridged for added stiffness and bent slightly to approximate the curvature of the arm. Layers of sponge rubber, $\frac{1}{4}$ in. thick and extending out about an inch beyond the edges of the aluminum strips were used as pads. The splints were attached to *S*'s arm by four straps, fastened around the fingers, wrist, elbow, and a point directly forward of the shoulder. The straps were adjusted so as to minimize movements at the joints of the arm without impeding circulation.

The accelerometer used for indicating changes in arm acceleration consisted of a 16-oz. Statham strain gauge with a 1-oz. weight mounted rigidly to the armature pin. The accelerometer was fastened to the center of the top splint with the triangular soft-iron bar attached midway between the accelerometer and the front end of this splint. The entire assembly which was strapped to *S*'s arm weighed 26 oz.

Tactual reaction time.—A hammerlike arrangement was used to deliver a tap to the back surface of *S*'s fingers. A lever was pivoted at one end on a ball-bearing axle attached to the same wall mount used for holding the electromagnet. The other end of the lever was fastened to a soft-iron bar which was held in position by the field of the electromagnet. The bar was $1\frac{1}{2}$ in. wide and 4 in. long, and fell a distance of $\frac{1}{8}$ in. with a force of 16 oz. upon *S*'s fingers. Pieces of $\frac{1}{4}$-in. lucite were cemented to the surface of the soft-iron bar which made contact with the magnet poles. This provided a noiseless release of the hammer when the magnet current was broken. The surface of the bar which made contact with *S*'s fingers was covered with masking tape to eliminate the sensation of cold metal. A piece of plywood was hinged to a block and held raised through a small angle by a spring so that *S*'s fingers were held parallel to the soft-iron bar. An accelerometer was mounted on the hinged board, so that when the weight touched *S*'s fingers the accelerometer was deflected to indicate the instant of contact.

Auditory reaction time.—The tone for the auditory stimulus was produced by a Jackson audio oscillator (Model 652). The frequency was set at 1000 cycles and the tone intensity, as measured at the approximate locus of *S*'s head by a General Radio Sound Level Meter (Type 759-B) was 72 db re .0002 dynes/cm.^{2}. The duration of the auditory stimulus was 300 msec.

Recording and measuring the responses.—All responses appeared as traces on a P-7, long persistence cathode-ray tube and were photographed on 35 mm. film by an Eyemo movie camera with a single-frame attachment. The *S* always responded to tactual and auditory stimuli by releasing a telegraph key, adjusted so that a minimum force of 200 gm. was required to hold the contacts closed. Two methods of indicating a response to the kinesthetic stimulus were used: (a) a key-release response, as described above for the tactual and auditory conditions, and (b) an arm-stopping response, in which change in arm acceleration was used as the indication.

Figure 1 presents photographs of the cathode-ray tube face, showing time and acceleration patterns of typical responses to the kinesthetic stimulus. The lettering has been superimposed on the records for explanatory purposes. Record 1 is the pattern produced by an arm-stopping response. The sweep starts at the left edge of the tube face and continues to *A*, where the magnet releases and the arm starts to fall. The nearly vertical line from *A* to *B* represents the very rapid change of arm acceleration from zero to a constant value. The distance from *B* to *C* represents the time during which the arm is falling at constant acceleration and is the measure of the reaction time. At *C* the trace leaves the horizontal as a result of *S* applying force to decelerate and stop his arm. Record 2 is the pattern produced by *S* indicating aware-

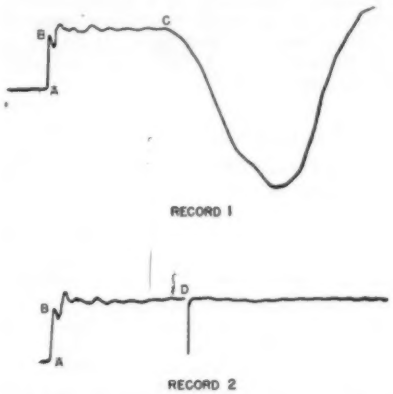

FIG. 1. Photographs of the cathode-ray tube face, showing time and acceleration patterns of typical responses to the kinesthetic stimulus. Record 1 is produced by an arm-stop response. Record 2 is produced by a key-release response.

ness of arm fall by releasing the key. This pattern duplicates that of Record 1 until point *D*. Here, instead of a deceleration, a pip appears signalling key release. Reaction time is measured from *B* to *D*. The trace continues horizontally beyond *D*, indicating that the arm continues to fall at constant acceleration, since *S* was instructed not to stop his arm in this portion of the experiment.

The cathode-ray tube pattern for the tactual condition shows a vertical displacement of the trace at the onset of stimulation which is produced by the weight striking *S*'s fingers and deflecting the accelerometer. A pip on the trace appears the instant *S* releases the key. The scope record for the auditory situation consists of two pips, one produced at the onset of the tone, the other when the key release occurs.

The sweep rate of the electron beam across the face of the cathode-ray tube was calibrated before the trials for each condition were presented. This was done by photographing the trace of a 110 cy./sec. sine wave on the face of the cathode-ray tube. The accuracy of this calibrating frequency was determined by using the 440 cy./sec. standard frequency broadcast from Station WWV, and adjusting the 110 cy./sec. oscillator so that a motionless 4–1 Lissajous figure was seen on an oscilloscope.

Timing.—Thyratron timers were used to provide the sequence of warning signal, foreperiod, and stimulus onset. The warning signal was a 60 cy./sec. buzzer which sounded for 200 msec. The foreperiod duration was randomly varied by *E* by means of a Helipot variable resistor on the foreperiod timer to give foreperiod durations between 1 and 3 sec. At the end of the foreperiod, the closing of the timer relay initiated the stimulus.

Experimental Procedure

Six Navy enlisted men who were assigned to the Laboratory to serve as *S*s were used in the experiment. Prior to the experimental runs, they were given two practice sessions, during each of which 35 trials for each of the four conditions were given. For some of the trials during the practice sessions, an assistant manipulated the control switch while *E* observed *S* and made comments to correct any faulty response movements. For the key-release *S* was trained to jerk his fingers off the key knob and hit an imaginary point about 6 in. above the knob. This technique resulted in a very fast key-release movement. The most important part of *S*'s training during the practice session was concerned with his learning to relax the arm held in the splints and not to tighten the arm muscles in anticipation of the magnet release. A stiffened falling arm was immediately apparent on the cathode-ray tube trace. The pattern (from *B* to *C* on Record 1 of Fig. 1) was not a horizontal line but had an irregular, wavy shape, indicating that acceleration was not constant during the fall. The *E* watched the pattern and described it over the speaker system to inform *S* of any faulty response movements.

Data were gathered during four sessions of 35 trials per condition, the first ten of which were practice and were not recorded. Thus, the results are based on 600 reaction time measures, contributed by six *S*s, for each of the four conditions. The order in which the *S*s were run and the order in which the four conditions were presented during each session were randomized. A 5-min. rest interval was interspersed between conditions.

To check certain of the results found with the experimental conditions as described above, a follow-up study was run. A new group of eight Navy enlisted men served as *S*s. The same procedures were followed as to practice, number of sessions, and number of trials per condition as that for the main experiment, except that only the kinesthetic stimulus conditions were used. For half of the sessions the key-release response situation was presented first, followed by the arm-stop response situation, and for the other half of the sessions the reverse order of conditions was used. The order in which each *S* was run and also the condition which was given first during each session was randomized.

The preliminary instructions to *S* as to warning buzzer and foreperiod were the same for all conditions. For the kinesthetic reaction time situation using the arm-stop response, *S* was instructed to make a quick upward movement to stop his falling right arm as soon as he was aware of the motion. For the key-release response to the kinesthetic stimulus *S* was instructed to release the key with his left hand as soon as he was aware of the motion of his right arm falling, but to permit the arm to continue its fall. For the tactual and auditory reaction time conditions, *S* was told to release the key with his left hand as soon as he felt the weight touch his right fingers or heard the tone. For all conditions *S* was instructed to keep his eyes closed during the presentation of the stimulus.

Since the cathode-ray tube had a long persistence screen, *E* could see the response trace as it was being photographed. If for any reason the response was not usable, an additional trial was given. For the entire experiment it was necessary to repeat less than 4% of the total trials for all conditions.

Results

The reaction time measures for each of the conditions for both the main experiment and the follow-up study are shown in Table 1. The various conditions were compared for statistical significance and Table 2 presents the results of the *t*-tests. The *t*-ratios were found by computing the mean reaction time for each *S* for his 100 responses and then determining the mean and *SD* of these *S* means, with the *SD* of the *S* means used in the *t*-formula for correlated variables. Five *df* were used for determining the *p*-values for the original experiment and 7 *df* were used for the follow-up study. The 5% confidence level was accepted as the criterion for statistical significance. The kinesthetic reaction time with the arm-stop response is significantly shorter than the auditory, tactual, or kinesthetic key-release reaction times. However, the latter three conditions do not differ significantly among themselves.

Examination of the data for evidence of learning from session to session revealed no significant trends. Thus it appears that sufficient practice was given for a stable condition to have been maintained for the duration of the experiment.

TABLE 1

Means and *SD*'s of Subject Mean Reaction Times in Milliseconds

Conditions	Main Experiment ($N=6$)		Follow-up Experiment ($N=8$)	
	Mean	*SD*	Mean	*SD*
Kinesthetic arm-stop	129.4	15.58	118.9	11.69
Kinesthetic key-release	149.6	18.91	152.9	15.96
Auditory	151.5	17.29		
Tactual	160.3	18.31		

TABLE 2

t-Ratios and Levels of Significance for the Various Conditions

Comparison	Diff. in Msec.	*t*	*p*
Main experiment			
Tactual vs. kinesthetic arm-stop	31.0	3.62	.02
Auditory vs. kinesthetic arm-stop	22.1	3.04	.03
Kinesthetic key-release vs. kinesthetic arm-stop	20.2	2.76	.04
Tactual vs. auditory	8.8	2.22	.08
Tactual vs. kinesthetic key-release	10.7	2.03	.10
Auditory vs. kinesthetic key-release	1.9	.40	.70
Follow-up experiment			
Kinesthetic key-release vs. kinesthetic arm-stop	34.0	8.06	.0001

Although the kinesthetic reaction time with the arm-stop response was significantly shorter than the other conditions, the absolute mean value of 118.9 msec. cannot be considered unusually short. This mean value is within the range of reaction times for other modalities. It is important to note here that the only condition differing significantly from the others was also the only condition in which a different method of response was used.

The kinesthetic reaction time means obtained for the original and follow-up studies were compared by means of *t*-tests and were found not to be significantly different for comparable response methods.

Discussion

The results clearly indicate that when *S* responded to the kinesthetic stimulus by the conventional key-release method, reaction time was of the order found for auditory and tactual stimulation and the values agree closely with the results reported by many other investigators (**6**).

Although the results showed a significantly shorter kinesthetic reaction time for the arm-stop as compared to the key-release situation, the reasons for this difference cannot be definitely determined. Several possibilities, however, may be suggested. One difference between the two situations was in the method of determining the onset of the response. When *S* stopped his falling arm, the onset was indicated by an accelerometer which produced a force pattern showing the change in arm acceleration. When *S* released a key, the onset of the response was taken as the instant of key contact separation. Birmingham and Tuthill (1) have shown that responses to an auditory stimulus measured from a force pattern at the point where *S* first changed the force applied to the key was significantly shorter than responses measured at the instant the key-contacts separated. Thus it seems likely that were our key-release responses taken from a force pattern curve, the differences in reaction time between the kinesthetic arm-stop situation and the various key-release situations would have lost their significance.

Other factors in the two situations which may have contributed to produce the difference in kinesthetic reaction time are: (a) the preferred hand was used to make the arm-stop response and the nonpreferred hand was used for the key-release; (b) in the arm-stop situation the kinesthetic stimulus originated in the same member used for responding, while for key-release the opposite member from that stimulated was used; and (c) in the arm-stop situation the responding member was in motion at the instant the response was initiated, while for the key-release the responding member started from rest.

In any event, whether the decrease in kinesthetic reaction time by use of the arm-stop response was due to an earlier "pick-off" of the response movement or due to the other factors mentioned above, the time measure which was obtained is still well within the range of reaction times for other modalities and cannot be construed to place kinesthetic reaction time in a unique category.

The results of this study are significant in light of the theoretical formulations which have been advanced regarding man's control of voluntary hand and arm movements. As mentioned previously, Taylor and Birmingham (8) have shown that visual information arising during the course of a short-duration hand movement is not utilized to guide that motion. The present study was to determine whether or not the kinesthetic reaction time was sufficiently brief to permit voluntary control through kinesthetic feedback.

It has been shown (7) that quick correction responses made in a tracking situation are completed within 350 msec. after starting. Analysis of the force pattern shows that braking force begins to be applied within 140 msec. of the start. The question arises as to whether kinesthetic impulses signalling the early phases of the response could go the round of the higher centers of the nervous system and control the application of the stopping force. The kinesthetic reaction time value of 118.9 msec. obtained in this experiment would seem at first to permit this, but further consideration renders this conclusion most unlikely.

It must be remembered that the reaction times measured in this study were simple and required no "choice." However, voluntary control of manual corrective responses on the basis of kinesthetic information would involve

"choice" reactions of a high order. Effectively, after *S* started his motion, he would have to receive the kinesthetic information concerning the very early accelerating phases of his response and then "choose" and put in a braking reaction which would decelerate his rapidly moving arm and bring his hand to rest on the point of aim. Though there is no basis for knowing exactly how much time this process of "discrimination and choice" would add to the simple reaction time, Woodworth (11) cites an example where the modification of a simple reaction time experiment into a two-choice test increased the reaction time by more than 125 msec. It seems certain that the task posed to *S* in the tracking situation is much more than a two-choice disjunctive reaction. This suggests that were our experiment on simple kinesthetic reaction time extended to the choice situation, the value obtained would have been too long to account for the initiation of the decelerating force 140 msec. after the beginning of the corrective motion.

This indicates that short duration motions of the hand and arm are accomplished by some means other than through continuous voluntary control based upon information furnished by feedback. Describing the process somewhat figuratively, it appears as if the *S* in a tracking situation perceives an error, selects a response pattern which is judged on the basis of past experience to be appropriate to null out the error and then triggers the complete sequence. The perception and selection require one reaction time. Once underway, the corrective motion runs a course determined entirely by reflex mechanisms and unmodified by voluntary impulses.

Such a description suggests that the volitional processes serve the function of intermittently issuing "orders," and that the nonvoluntary, lower center mechanisms execute these orders without additional voluntary guidance. Thus, tracking, and possibly other forms of voluntary behavior, could be viewed as a sequence of voluntarily selected, reflexly controlled acts.

If this view of the control of behavior is at all correct, it is apparent that any simple servo analogy is quite inadequate to describe human response. The simplest mechanical analogy would require some type of intermittent ordering device in addition to a responding mechanism. The nature of both of these components can hardly be specified at this time.

Summary

To determine the role of kinesthesis in the control of precise hand and arm movements, it is first necessary to know how rapidly a human can respond to a kinesthetic stimulus. This study was an attempt to determine the reaction time to a kinesthetic stimulus initiated by suddenly dropping *S*'s splinted arm which was held horizontally by an electromagnet. In one situation *S* responds by releasing a key with his other hand upon awareness of arm fall, and in the second situation he responds by stopping his falling arm as quickly as possible. For purposes of comparison, auditory and tactual reaction times were obtained, with the key-release as the response.

The kinesthetic reaction time with the arm-stop response differed significantly from the other three conditions; no other differences were significant. The difference in kinesthetic reaction time with the arm-stop response and the key-release response was confirmed by a supplementary study.

The shorter kinesthetic reaction time obtained with the arm-stop re-

sponse is probably a function of the use of an accelerometer to indicate the onset of the response. However, it is still within the range of reaction times for other modalities.

It is concluded that kinesthetic reaction time is too long to permit continuous voluntary control of short-duration hand and arm movements by information furnished through feedback. A dual mechanism of control is suggested, wherein the volitional processes serve the function of intermittently issuing "orders" and the nonvoluntary, lower centers execute these orders without additional voluntary guidance.

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FURTHER STUDIES OF PERCEPTION OF THE UPRIGHT WHEN THE DIRECTION OF THE FORCE ACTING ON THE BODY IS CHANGED[1]

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A previous study (**6**) of perception of the upright during rotation was one of a series in which the two main standards for determining the upright (the visual and gravitational) have been separated in order to determine the specific role of each. In that study such separation was achieved by rotating *S* about a circular path; for during rotation the direction of the force acting on the body is altered, thereby changing the gravitational standard. In other studies (**4, 7**) the separation had been accomplished in a converse way, by tilting the visual field while the direction of the force on the body remained unchanged.

In order to establish exactly the location of *S*'s perceived upright during rotation, he was required to adjust a rod on the front wall of the room in which he was riding to a position which he perceived as upright. This rod-adjustment procedure featured perception of the direction of an item within a field. It did not permit study of *S*'s perception of body position or position of the whole surrounding field during rotation. To observe these important aspects of perception of the upright, *S* must be able to adjust his body and the rotating room; but this was not possible with the apparatus used. For the present investigation a device was developed that permitted room adjustment and chair adjustment; and with this device a study has been made of perception of body position and field position during rotation.

Apparatus

The apparatus consisted of a small, fully enclosed, lightproofed room, mounted on a chassis that was driven about a circular track (Fig. 1). This room was 5 ft. high by 5 ft. wide by 4.5 ft. long, and was secured to the chassis by means of trunnions. It could be tilted from side to side on the chassis on an axis that made a tangent with the circle of rotation, and it contained a chair that could also be tilted to one side or the other on the same axis. The rotation of the whole unit, and the tilting of room and chair, were controlled by *E* from a remote control panel.

Remote control of room tilt and chair tilt was achieved through the use of Allis-Chalmers positioner units, consisting of a transmitter and receiver. The primary source of power was 120-v. DC introduced at the transmitter. With these units no power is needed to turn the transmitter other than that required to overcome bearing friction. The receiver keeps in perfect step with the transmitter, rotating at the same speed. The receiver is capable of delivering the required torque through a worm-gear reducing system.

One positioner unit was employed to tilt the room, the other to tilt the chair. The receivers of both were mounted on the chassis, and were connected through worms and worm gears to the shafts that tilted the room and the chair. The shaft for the chair was located inside the hollow room shaft. The wiring for the receiver was brought to the rotating unit through a slip-ring assembly.

The remote control panel contained the two transmitting units, coupled through spur gears to the small, constant speed, reversible motors used to drive them. Each motor was controlled by a double-pole switch, one pole for clockwise rotation and the other for counterclockwise

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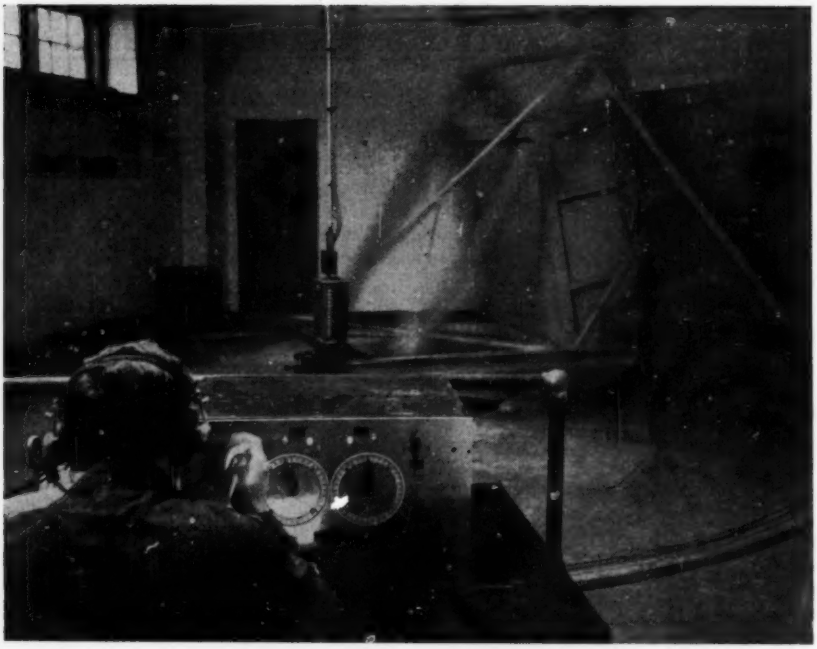

FIG. 1. The rotating-room apparatus

rotation. Indicator pointers that moved against stationary protractors showed the positions of room and chair in degrees at any given moment. Dry-disc rectifiers were used for converting AC to DC. The room was tilted to left or right at a rate of 3.8° per sec. and the chair at a rate of 1.8° per sec.

The aluminum chassis rested on two standard automobile wheels with 6.00 × 16 pneumatic tractor tires. The wheels rode on a heavily waxed level wooden track, 22 ft. in diameter. The center of *S*'s chair was 7 ft. from the center of rotation. The end of the chassis opposite to that on which the room sat rested on a central driving pivot consisting of a ratchet-and-pawl drive and a 48:1 worm-gear reducing unit. The ratchet and pawl prevented sudden stopping when the power was removed from the worm-gear reducer. Connected to the reducer through a V-belt drive was a 5-h.p. wound rotor-induction motor, which was also controlled from *E*'s table. The speed of the motor, and consequently the rate of movement of the experimental room around the track, was varied by means of a 3-phase rheostat in the rotor circuit of the motor.[2]

A modified public address system, with a foot control for talk-listen switching located under *E*'s table, enabled *S* and *E* to communicate with each other. A loud-speaker inside the room on its front wall, served as both speaker and microphone for *S*. For ventilation, inlet and exhaust fans were mounted in the bottom of the rear wall and the top of the front wall of the room.

The interior of the room was painted a dull black, except for the ceiling, which was lined with white sound-absorbing squares. Each wall was bordered with 1-in. white strips, and

[2] The speed of the motor was checked during the course of the test by means of an electric tachometer. The tachometer generator was coupled to the shaft of the drive motor and the indicator was mounted on *E*'s control panel. Whenever changes occurred in the speed of the motor, owing to fluctuations in the house current, *E* adjusted the rheostat to compensate for the change.

the front wall had, in addition, a white horizontal strip running across the middle. Two framed pictures, each 8¾ in. × 10¾ in., were mounted on either side of the front wall, near the ceiling. The white strips and pictures were introduced to provide prominent vertical and horizontal lines. The front wall also had the speaker-microphone unit at its center, the exhaust fan above it, and a shaded luminous bulb near the ceiling. A switch on *E*'s control panel enabled him to turn this light off, leaving *S* in complete darkness and thereby eliminating the visual field. Finally, a door through which *S* could enter and leave the experimental room was located at the front end of the right wall.

The chair in which *S* sat was provided with a headrest and a footrest. It had L-shaped side supports, the "base" portion 9 in. high along the sides of the seat, and the "shaft" portion 5½ in. wide and as high as the back of the chair. This provided arm rests, as well as supports for both the lower and upper parts of *S*'s body when the chair was tilted. The back, seat, and lower sides were padded.

Procedure

The apparatus was brought to a uniform rate of rotation while *S*'s chair and the room remained in an objectively upright position. The *S* was then required on some trials to "straighten" his chair if his body felt tilted, and on other trials to "straighten" the room if it looked tilted. The amount by which he moved each item from its initial upright position in order to perceive it as straight was a measure of the effect on his perception of the change in the direction of the force acting on his body.

Tests were conducted at four different speeds of rotation: 12.8, 15.0, 16.7, and 18.8 rpm. At these speeds the effective force on the body was displaced from the true vertical at angles of 21.1°, 28.8°, 33.5°, and 39.9°, respectively.

A different group of *S*s was used for each rate of rotation, and regardless of the rate employed every *S* received three series of four trials each: *Series 1.*—The experimental room had to be adjusted to a position in which *S* perceived it as upright, while the chair remained in its initial position. *Series 2.*—The chair had to be adjusted to a position in which *S* perceived his body as upright. The lights in the room were on, and the room remained in its initial position while the chair was moved. *Series 3.*—Again, the chair had to be adjusted, but with the room darkened, so that no visual field was present.

The 12 trials of the test were presented in two sets of six trials each, with a 3-min. rest period between them, during which rotation was stopped. In each set, the three test conditions enumerated above were presented in the sequence 3, 2, 1, 1, 2, 3.

The *S* was blindfolded when he was brought into the laboratory and seated in the rotating room. This prevented him from determining in advance the nature of the movement to which he was to be subjected. The door of the room was closed, the blindfold removed, and *E*, who had remained in the room for this purpose, read the following instructions:

"In this test we want to find out how well you can keep your bearings under various conditions. In a moment I will step out of this room. We have a communication system, however, so that we will be able to speak to each other while I am outside.

"I am able to do various things to your chair and to the room that you are in. We are interested in finding out how well you can tell when the chair and the room are straight. What we will do is this: If you think your chair or this room is tilted, we will straighten it. On some trials we will be concerned with the chair only; on other trials we will be concerned with the room only. If you think they are straight at the very beginning, we will leave them as they are.

"Let me tell you at this point what I mean by straight. When your chair is straight, it should be lined up with the walls of Ingersoll [the laboratory building] outside, and you should be sitting straight up and down the way you are right now. When the room is straight, its walls should be lined up with the walls of Ingersoll outside, the way they are now, and its floor should be straight with the floor of Ingersoll outside, the way it is now. In other words, when the room is straight, it should be standing exactly the way it is right now. Are there any questions?

"Our procedure will be as follows. I will ask you what your position is. If you tell me you are tilted, and also the direction in which you are tilted, I will move you from the outside until you think you are straight. I will move you a little bit at a time. After each turn, tell me whether you have been moved enough or whether you want to be moved some more. Just keep on saying 'more,' 'more,' 'more,' until you think that you are straight, and then say 'enough.' As I said before, at other times your task will be to judge the position of the room. If you think the room is not straight when I ask its position, I will move it until it is straight. Again, keep saying 'more,' 'more,' 'more,' until you think that the room is straight, and when it is straight, just say 'enough.' Are there any questions?

"There is one other point. On some trials,

the lights in this room will be turned on, and on other trials they will be turned off. When the lights are on, your eyes should be open. When the lights are off, your eyes should be closed. I will tell you before each trial whether the lights will be on or off. I will say either, 'Lights off, eyes closed,' or 'lights on, eyes open.' "

The headrest was then adjusted very tightly, to prevent any head movement whatever, and *E* stepped out of the apparatus and set the unit in rotation. After the room had gone through one full rotation at maximum speed, *E* turned off the lights and proceeded with the first trial (Series 3). He tilted the chair 5° left, returned it to 0°, and asked *S* to indicate his position.[3] If *S* reported that he was tilted, the chair was moved in 2° steps away from the reported direction of tilt; and when he indicated that it was straight, he was asked, "Is your chair now straight with the walls of the building out here, so that you are sitting straight up and down the way you were when you came in?" This question was repeated after each chair-adjustment trial.

The chair was now tilted 6° to the right of the position in which it was reported to be straight, and returned to 0° for the second trial. While this was being done, *S* was asked, "How do you like this?" in order to give him an opportunity to indicate whether he was feeling ill.

The same procedure was followed in all subsequent chair-adjustment trials. On trials given with lights on, the lights were turned off after *S* had adjusted the chair to what he perceived to be an upright position, and turned on again when it had been returned to 0° for the next trial.

On each room-adjustment trial, if *S* reported that the room (which was objectively at 0°) appeared tilted, it was moved 4° at a time until he reported it to be straight. He was then asked: "Are the walls of the room now straight with the walls of the building out here, and is the floor of the room that you stood on when you came in now straight with the floor out here, so that the room is standing the way it was when you came in?" After each room-adjustment trial, the lights were turned off, the room returned to 0°, and the chair, after being tilted 6° to the right, was also returned to 0°.

At the end of the first six trials, rotation was stopped, and after a 3-min. rest, another six trials were given. After the test, *S* was questioned carefully about how he had judged the position of room and chair, how he had felt during the test, whether he had known that the apparatus was rotating, and, if so, how he had used this knowledge in making his judgments.

Some *S*s became ill during rotation, exhibiting such symptoms as sweating, dizziness, nausea, and even vomiting. The following precautions, already mentioned, were designed to reduce the incidence of illness to a minimum, and to alleviate symptoms when they occurred. (a) The tight-fitting headrest prevented head movements, which during rotation might induce Coriolis reactions. If permitted to occur, these reactions result in illusions of body and field movement, which not only affect perception of the upright but also tend to make *S* ill. (b) The experimental room was ventilated during rotation. (c) Each time rotation was begun, the experimental room was lighted. We have observed that this tends to make the experience of rotation less disturbing than if it is begun in darkness. (d) At all times, movement of the chair was carried out in small steps. This has been found less disturbing than continuous movement. (e) A rest period was provided halfway through the test. (f) During each trial *S* was asked, "How do you like this?" This neutral question gave him an opportunity to indicate whether he was feeling ill, and enabled *E* to stop rotation before *S* became seriously affected. Despite these precautions nausea of varying degrees of severity and occasionally vomiting occurred in more than a third of our *S*s. In a small number of cases it was necessary to discontinue testing because of illness. When this happened, the test was completed after a short rest or on a later occasion, but some *S*s refused to submit to further testing. These latter *S*s have, of course, not been included in our study.

The *S*s used in this study were volunteers from the introductory psychology classes at Brooklyn College. The number of males and females tested at each of the rates of rotation is given in Table 1.

Results

Table 1 presents for each of the three experimental series at the four different speeds of rotation the error scores, which represent the number of degrees by which the room (Series 1) or the chair (Series 2 and 3) varied from the true upright when reported to be straight. The relation between rate of rotation and magnitude of

[3] This preliminary procedure caused *S* to experience displacement to the left in addition to the displacement to the right that he had felt as a result of the rotation, and provided a "reasonable" basis for him to move the chair in *either* direction in his subsequent adjustments.

TABLE 1

DISTRIBUTIONS OF INDIVIDUAL MEAN SCORES, GROUP MEANS, *SD*'S AND *N*'S FOR EACH TEST CONDITION

Mean Error (in Deg.)	Series 1 Room Adjustment, Eyes Open								Series 2 Chair Adjustment, Eyes Open								Series 3 Chair Adjustment, Eyes Closed							
	Rate of Rotation (RPM)								Rate of Rotation (RPM)								Rate of Rotation (RPM)							
	12.8		15.0		16.7		18.8		12.8		15.0		16.7		18.8		12.8		15.0		16.7		18.8	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0–3	3	11	4	4	1	7	1	5	7	14	1	6	1	5	1	2	...	...	...	...	...	...	...	...
4–6	9	8	3	9	4	...	5	6	9	7	10	7	6	4	5	2	1	1	...	...	...	...	...	...
7–9	8	7	8	6	5	3	1	5	10	7	6	8	3	4	3	15	6	6	...	...	...	...	...	...
10–12	6	3	4	5	3	9	7	11	1	2	4	5	3	4	3	10	8	13	2	...	1	1	...	...
13–15	3	1	2	1	2	3	10	6	3	...	3	2	3	4	4	8	10	7	3	2	2	1	1	3
16–18	1		3	2	4	2	4	5			2	1	4	1	4	6	4	3	8	1	1	6	6	3
19–21			1	2	3	1	3	3			1	...	1	...	1	5	1		6	5	7	4	7	6
22–24			...	...	1	3	1	2			...		2		3	2			5	8	5	5	15	5
25–27			2	1	1	1	5	1			1		1		1				2	7	8	6	5	7
28–30					1		4	1					...		2				1	3	4	11	7	2
31–33					...		1	1												3	5	4	2	2
34–36					...		1	1												1	1	2		
37–39					1			1																
40–42								1																
Mean	7.8	5.1	10.2	8.8	15.0	11.7	17.5	13.0	5.8	4.5	8.8	7.8	13.0	10.8	16.1	12.1	11.8	11.3	15.2	18.2	21.4	21.8	23.6	22.4
SD	3.8	3.6	6.4	6.0	9.2	7.9	9.4	7.6	3.5	2.9	4.5	4.9	7.2	6.6	7.4	5.7	3.1	2.7	4.5	4.6	5.4	5.2	6.5	5.6
N	30	30	27	30	27	30	45	50	30	30	27	30	27	30	45	50	30	30	27	30	27	30	45	50

shift of the perceived upright is shown graphically in Fig. 2, where the mean error scores for each of the three experimental series have been plotted against rate of rotation (rpm). Also included in Fig. 2 is a curve representing the relation between rate of rotation and magnitude of shift of the effective force acting on the body.

It may be seen, first of all, that all mean error scores are greater than zero and often fairly large, indicating that when room and body were in objectively upright positions, *Ss* tended to perceive them as tilted, and in order to perceive them as straight, tilted them from the true upright. Since the direction of apparent tilt of room and chair in their initial positions was away from the center of rotation when they were perceived as tilted, *Ss* almost invariably tilted them toward the center of rotation in attempting to make them straight.[4]

In Series 1 and 2, *S* was required to adjust room and chair, respectively, so that he perceived them as upright and he had to carry out these tasks with conflicting visual and postural standards. If he accepted the vertical of the visual field as representing the true vertical, he would at once perceive room and chair as straight in their initial objectively upright positions, and would therefore not move them at all. His score would thus be 0°.[5] Conversely, if his perception of the vertical was derived entirely from the direction of the force acting on his body, he would align the room with this force, or tilt it by the number of degrees that the force has been shifted from the upright at the given rate of rotation. The average position to which the room was moved in Series 1 and the chair in Series 2, at each of the four rates of rotation, indicates that *Ss* tended to compromise between these conflicting standards in establishing the upright—coming closer, however, to the visual standard. In Series 3, *S* again had to adjust his chair, but now the shifted gravitational standard alone remained as a basis for perception. Here *Ss*, on the

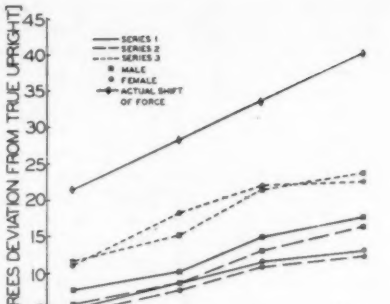

FIG. 2. Relation between rate of rotation and deviation of the perceived upright from the true upright for the three experimental series

[4] In Series 1 the room was tilted away from the center of rotation in order to be perceived as straight in only 5 of the 1076 trials given at the four rates of rotation. One trial occurred at the 15.0-rpm speed, 2 at the 16.7-rpm speed, and 2 at the 18.8-rpm speed; the room was tilted 5°, 1°, 4°, 4°, and 2°, respectively, on these trials. In Series 2, the chair was tilted away from the center of rotation in only 2 of 1076 trials, once at the 15.0-rpm speed and once at the 18.8-rpm speed; it was tilted 1° and 4°, respectively. Finally in Series 3 tilting of the room away from the center of rotation never occurred at all. On some other trials, as will be seen later, the room or chair was reported as straight in its initial position, so that it did not need to be moved at all.

[5] This would be true when the chair is to be adjusted (Series 2) even if *S* perceived the room itself as tilted in the 0° position. When the vertical axis of the surrounding field provides the main frame of reference for determining body position, the important thing is whether or not the body is aligned with this axis; and the body will *look* tilted when out of line with the room's vertical, regardless of whether or not the room is straight.

average, required their bodies to be farther from the upright than in Series 2 in order to perceive them as straight. The fact that the body had to be tilted so much more in Series 3 indicates that it felt more tilted in its initial 0° position. Thus, while rotation generally causes the body to feel tilted, the apparent tilt is considerably greater in the absence of a visual field than in the presence of an objectively upright field.

It may also be seen from Fig. 2 that the curves for Series 1 and 2 tend to cluster together and to remain throughout their course a good deal below the level of the Series 3 curves. A comparison of mean scores for the three series at each of the four rates of rotation reveals that the scores for Series 1 and 3 are significantly different in every case for both men and women. The same is true of the scores for Series 2 and 3. On the other hand, with only one exception (men, 12.8-rpm rate), the scores for Series 1 and Series 2 are not significantly different. There was thus a clear tendency for *S*s to locate the upright in about the same position when conflicting visual and postural standards were available (Series 1 and 2), regardless of whether the location was indicated by adjusting the surrounding field (Series 1) or the body itself (Series 2). The upright was located in a different position when the postural standard alone was available (Series 3); and that position was farther away from the true upright.

It may be noted in Fig. 2 that for Series 1 and 2 the curves for men tend to remain above the level of the corresponding curves for women. Apparently, women rely less on bodily experiences, or adhere more strongly to the standard offered by the visual field, in determining the upright. Though there are differences between men and women in this direction at each of the four speeds in both series, they are greatest at the highest speed (18.8 rpm) and it is only at this speed that the sex differences are significant for both Series 1 and 2. At the 16.7- and 15.0-rpm speeds, the sex difference is significant for neither series; at the 12.8-rpm speed it is significant for Series 1 only. Apparently, though present at all speeds, this difference between the sexes becomes most prominent at the highest speed, when the force on the body suffers its greatest shift from the true upright and the conflict between the visual and postural standards is most pronounced.

The relation between the scores for men and for women in Series 3, on the other hand, where the postural standard alone was available, is very different. The mean error scores for the two sexes are almost identical, except at the 15.0-rpm speed of rotation, and in fact at two of the four speeds the mean scores for women are higher. This finding suggests that when a postural standard alone is available, men and women use it in a very similar fashion. On the other hand, when a conflicting visual standard is also present, both men and women reduce their reliance upon the postural standard, but women adhere to the visual standard to a greater extent than do men.

From the curves in Fig. 2 it is clear that as the rate of rotation increased, so that the force on the body was displaced farther from the true upright, there was a progressive increase in the magnitude of shift of the perceived upright from the true upright. This was true whether *S* adjusted the room (Series 1) or adjusted his own body (Series 2 and 3); and it held for both men and women.

It may also be seen in Fig. 2 that

the average displacement of the perceived upright was not nearly so great, at any speed, as the actual shift of the force acting on *S*'s body. Where no visual field was present (Series 3), the difference was smaller than in Series 1 or 2, but in all series it was greater at higher than at lower speeds. Finally, the curves for the three series are not linear in form, but have a tendency to level off at the higher rates of rotation, so that a given increase in rate of rotation causes smaller shifts in the perceived upright at higher speeds than at lower speeds.

The *SD*'s in Table 1 indicate that *S*s were most nearly alike in their performances at the lowest speed used; and they were most different from one another at the highest speed used. Particularly at the higher rates of rotation, the range of scores was wide, reflecting marked individual differences. For example, at the 18.8-rpm rate in Series 1 one man and five women reported the room to be straight when it was in about the true upright position, thus accepting the room's vertical as the true vertical in the initial position in which it was presented to them. At the other extreme was a man who tilted the room, on the average, more than 40° from its initial upright position in order to perceive it as straight, thus establishing the upright entirely in accordance with the direction of the force acting on the body. In contrast to these extreme adjustments, most *S*s brought the room to a position somewhere between the visually and posturally indicated uprights.

An examination of *S*s' verbal reports helps account for these marked individual differences. The *S*s differed markedly in their impressions of the initial positions of room and chair. For many *S*s the room in its initial objectively upright position actually *looked tilted* during rotation, in a direction away from the center of rotation; but the extent of apparent tilt varied greatly. For other *S*s, however, the room tended to *look straight* in its initial position, despite the rotation. The percentage of male *S*s who perceived the room as fully upright in its initial position on one or more of the eight trials of Series 1 and 2 was 40.0%, 40.7%, 11.1%, and 33.3% at the 12.8-, 15.0-, 16.7-, and 18.8-rpm rates, respectively. For women, the corresponding values for these four rates were 63.3%, 70.0%, 43.3%, and 38.0%.

Differences in perception of body position at the beginning of each trial are also revealed by *S*s' reports. The great majority of *S*s perceived the body (and chair) as tilted in its initial objectively upright position on all trials of Series 1 and 2, although the extent of apparent tilt differed greatly. Some *S*s, however, perceived their bodies as fully upright on some trials. The percentage of males who perceived their bodies to be straight at the very outset on one or more of the eight trials of Series 1 and 2 was 30.0%, 22.2%, 7.4%, and 17.7% at the 12.8-, 15.0-, 16.7-, and 18.8-rpm rates. For women the values for these four rates were 30.0%, 43.3%, 20.0%, and 16.0%. The *S*s who perceived their bodies as only slightly tilted were using the objectively upright field alone and were disregarding the intense lateral tug exerted on the body; those who perceived the body as very tilted were determining its position with reference to the force acting upon it. Thus, under conditions of sensory conflict, *S*s varied in their immediate impressions of body and field, even though the direction of the force acting on their bodies and the position of the field were the same for all of them.

In Series 3, where postural experiences alone were available for determining body position, *S*s almost without exception perceived their bodies as tilted at the beginning of every trial.[6] Moreover, they usually felt more tilted in this condition than in Series 2, where the field could be seen and used as an additional basis for establishing body position. At the same time, even here, *S*s differed as to the amount of perceived tilt.

Having established that there are marked individual differences in manner of establishing the upright during rotation, we next determined their reliability. Odd-even correlations were computed for each of the three series at the four rates of rotation (Table 2). The values are in general quite high and are significant at the 1% level of confidence, indicating that each person tended to establish the upright in a consistent manner on

[6] At the 12.8-rpm rate there were three male *S*s and one female *S*, and at the 15.0-rpm rate there were one male *S* and one female *S*, who perceived the body as straight on one trial each. At the two highest speeds (16.7- and 18.8-rpm) no *S* ever perceived the body as straight in its initial position at the beginning of a trial.

TABLE 2

UNCORRECTED ODD-EVEN CORRELATIONS FOR EACH TEST CONDITION*

Series	Rate of Rotation (RPM)							
	12.8		15.0		16.7		18.8	
	M	F	M	F	M	F	M	F
1. Room adjustment, eyes open	.72	.81	.92	.86	.95	.77	.89	.86
2. Chair adjustment, eyes open	.87	.88	.81	.87	.94	.87	.89	.78
3. Chair adjustment, eyes closed	.64	.59	.75	.79	.90	.76	.81	.63

* All correlations are significant at the 1% level of confidence.

the different trials of each series. The correlations for Series 3 are lower than these for Series 1 and 2.

The relations among the three series of the test may be determined through the correlations presented in Table 3. For both men and women, the highest correlations generally occur between the two chair-adjustment series (Series 2 and 3), the lowest between Series 1 and 3. This latter relationship is to be expected, since these two series differ both in the nature of the task to be carried out (room-adjustment vs. chair-adjustment) and in the standards available for judgment (visual and postural vs. postural alone).

TABLE 3

INTERCORRELATIONS AMONG THE TEST CONDITIONS

Rate of Rotation (RPM)	Series 1 vs. Series 2		Series 1 vs. Series 3		Series 2 vs. Series 3	
	M	F	M	F	M	F
12.8	.48**	.60**	.44*	.36	.66**	.42*
15.0	.56**	.79**	.55**	.57**	.61**	.53**
16.7	.72**	.61**	.59**	.49**	.65**	.72**
18.8	.60**	.31*	.47**	.22	.75**	.46**

* Significant at the 5% level of confidence.
** Significant at the 1% level of confidence.

DISCUSSION

An earlier study (6) investigated the effect of rotation (i.e., of changing the direction of the force acting on the body) upon perception of the position of an item in the field. In the experiments described here, we considered the effect of rotation on the perceived position of the body itself and of the whole field. Together, these two studies cover the three main aspects of orientation toward the upright.

Whichever of these aspects is featured in a given experimental situation, the position to which *S* brings the item which he is asked to make straight (a rod, his body, or the surrounding field) represents the location of his perceived upright. The results for the different experimental situations investigated in these two studies may therefore be pooled in determining the effect of rotation under various conditions upon perception of the upright. It is apparent from these results, first of all, that when the force on the body is shifted from the true gravitational upright by rotation, and an upright visual field is present, the perceived upright is derived more from the visual standard than from the postural standard. In the absence of a visual field, on the other hand, the perceived upright is based more closely on the postural standard. In other words, in the absence of a field, rotation causes a considerably larger deviation of the perceived upright away from the true upright and toward the direction of the force acting on the body, than it does with a field present.

A second generalization is that as the rate of rotation increases, so that

the force on the body is displaced farther from the true upright, the perceived upright also is shifted farther from the true upright. There is some evidence (Fig. 2) that the relationship is not linear, however.

Thirdly, our results show that under each type of experimental condition there are marked individual differences in performance. Different *S*s reported the rod (or the body, or the field) to be straight not in a single position but over a wide range of positions. This was true even in tests made in the absence of a field, when the direction of the force on the body provided for everyone the sole standard for establishing the upright.[7] In addition to these individual differences, differences between men and women have also been noted. These occurred only when conflicting visual and postural standards were available; and they appeared most prominently at the highest rate of rotation, when the discrepancy between these standards was particularly great. The observed tendency of women to adhere more strongly than men to a standard derived from the prevailing visual field under conditions of conflict has been noted in a variety of other situations as well (**5**); and in these situations again sex differences did not occur when perception was based on a single standard.

Although the generalizations cited above hold true for all the experimental conditions investigated, there were some differences in results related to the nature of the particular aspects of upright orientation involved. In Table 4 are shown mean error scores obtained in the earlier rod-adjustment study and in the chair-adjustment tests of the present study, at two different rates of rotation, with and without a visual field.

TABLE 4

COMPARISON OF MEAN ERROR SCORES FOR ROD-ADJUSTMENT AND CHAIR-ADJUSTMENT TESTS*

Adjustment	Visual Field Present		Visual Field Absent	
	Speed A**	Speed B***	Speed A	Speed B
Rod	3.1	6.3	10.7	24.7
Chair	5.2	11.8	11.6	21.6

* Combined results from men and women.
** Actual displacement of force on the body was 20.5° with rod, 21.1° with chair.
*** Actual displacement of force on the body was 33.4° with rod, 33.5° with chair.

The scores show that when a visual field was present the rod was tilted considerably less from the upright of the field than was the body. This finding reflects the fact that the position of an external item such as the rod is determined by *S* predominantly on a visual basis, i.e., by its relation to the surrounding field. Perception of body position, on the other hand, depends much more upon specific bodily experiences, which are affected by rotation, and is less influenced by the surrounding field. Table 4 also shows that when the visual field was eliminated, and the postural standard alone remained, no such differences between manner of adjusting the rod and manner of adjusting the body occurred. At Speed A the body was tilted only slightly more than the rod; at Speed B the body was tilted somewhat less than the rod. The simliarity in these

[7] The wide range of performances found here and in our previous investigations points to the need in perceptual studies of an adequate number of cases if valid generalizations are to be reached. Thus, if in the present study we had tested just a few subjects, and these had chanced to come from one or the other extreme of the performance range, we would have been led to incorrect conclusions. In view of this, the evidence from several recent studies on perception of the upright during rotation (**1, 2, 3**) cannot really be evaluated, since in each the evidence was based on only three or four subjects.

results indicates that in the absence of a field, rod adjustment and body adjustment were both carried out on the basis of the same single standard.

It has been noted that in the absence of a visual field (Series 3) the average amount by which the body was tilted fell short of the amount of change in the angle of force on the body. This was true at all four rates of rotation. One partial explanation of this failure of *Ss* to align themselves with the force on the body under the conditions of Series 3 is suggested by a finding reported in an earlier study (**4**). There, *S* was blindfolded, his chair was simply tilted to one side, and he was required to bring it back to the upright position. It was noted that *Ss* tended in varying degrees to leave the body displaced to the side of its initial tilt, and this was ascribed to a negative after-effect of body tilt. When straightening of the body was carried out by *E* in a stepwise procedure, the position to which the body was brought fell short of the gravitational upright by an average of 7.1°. This negative after-effect undoubtedly occurred in the chair-adjustment trials of the present experiment as well. If its magnitude is taken to be 7.1°, it would account at the two lower rates of rotation for practically all the discrepancy between the amount of body tilt and the amount of shift of the force acting on the body; and it would account for a good portion of the discrepancy at the two higher rates of rotation.

The results for Series 2 and 3 indicated that to be perceived as upright during rotation the body had to be tilted a good deal more without a visual field than with a field. Thus, the body in a given position actually *felt* straight or tilted, according to whether or not it was surrounded by an upright field. Dependence of the perceived position of the body on visual impressions was noted in an earlier study as well (**4**). There, too, contradictory bodily sensations of tilt were found to be suppressed when, because of its alignment with the field, the body *looked* straight. There is thus additional evidence that the perception of body position cannot be understood in terms of postural cues alone, but also requires reference to the visually indicated relation between the body and the surrounding field.

Summary

Supplementing an earlier study (**6**) of perception of the position of an item within a field during rotation (i.e., during displacement of the direction of the force acting on the body), this study investigated the effect of rotation upon perception of the position of the body itself and of the surrounding field. The apparatus consisted of a small fully-enclosed room which moved around a circular track. Both room and a chair within it could be tilted left and right, either together or independently. The *S* was required on some trials to "straighten" the room if it appeared tilted, and on other trials to "straighten" his body if it felt tilted. Adjustment of the body was made with the room lighted and darkened (i.e., with and without a visual field). Data were obtained for four rates of rotation, a different group of young adult *Ss* being used for each speed.

During rotation the *room* usually had to be tilted from the true upright toward the center of rotation to be perceived as upright. The average amount by which the room was tilted, however, was considerably less than the magnitude of the shift of the force on the body. It was found that the

body also usually had to be tilted toward the center of rotation to be perceived as upright. It was tilted much less, however, when an objectively upright field was present than without a field.

In general, the location of the perceived upright was quite different with a visual field than without one. When an objectively upright field was present, the perceived upright was located closer to the vertical of the field, i.e., the true upright, than to the direction of the displaced force acting on the body, whereas without a field it was placed closer to the force on the body. With increase in the rate of rotation an increase in magnitude of shift of the perceived upright from the true upright occurred under all conditions. This relationship does not seem to be linear.

Marked individual differences were observed among *Ss* in manner of locating the upright. In judgments of field position and body position made with conflicting visual and postural standards, some *Ss* relied almost exclusively on one or the other of these standards, while other *Ss* compromised between them in varying degrees. In judgments of body position made with a postural standard alone, *Ss* differed in the degree to which the body was aligned with the displaced force acting upon it. Differences in perception between men and women were also noted under conditions of conflicting visual and postural standards, with women adhering more closely to the visual standard.

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THE INFLUENCE OF MASSED AND DISTRIBUTED PRACTICE ON THE DEVELOPMENT OF MENTAL SET

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The effects of distribution of practice have been extensively investigated in *simple* learning situations. An examination of the experimental data would appear to justify the conclusion that some form of distributed practice is superior to massed practice (2). The purpose of the present investigation is to discover whether such a generalization may be applied to the learning of a mental set in a problem-solving situation.

METHOD

Experimental design.—The experimental procedure utilized in this study was a modification of the technique reported by Luchins (1). Simple problems involving three jars of various capacities were individually presented to *S*s who were instructed to obtain a specific quantity by the appropriate manipulations of the containers. A set solution to all problems was developed during the training series by insuring its successful utilization. The strength of this set response was measured by a test problem which could be either solved in the set manner or more simply and adequately by a direct method. Half of the *S*s (Group D) had a 3-min. interval between successive training problems while the remaining half (Group M) had a zero time interval.

Subjects.—The *S*s were 100 undergraduate male students from the University College of Arts and Science of New York University.

Procedure.—The arithmetical problems used are shown in Table 1.

The problems were presented in a concrete manner. A set of 16 containers, each in the shape of a cube made of 24-gauge galvanized iron, was used. On each container was clearly labeled the capacity in cubic inches. Each problem was presented by having the appropriate containers placed on an aluminum tray, 12 by 16 in. An ordinary glass pitcher with one handle and a wide lip served as the storage receptacle.

The series of problems was individually administered by the junior authors. The *E* read the following instructions to each *S* immediately prior to his experimental session:

"You will receive a number of numerical problems. Each involves measurement of definite amounts of beans by means of *all* or *any* of the containers. In all these problems you will be presented with a number of containers. The numbers on these containers represent the capacity of the containers in cubic inches. You will also be given a card stating the amount of beans you are to obtain. Here is the first problem. There is an empty 29-cu. in. container and an empty 3-cu. in. container, as well as a large quantity of beans in this container. You are to obtain 20 cu. in. of beans. Here is the card stating the amount of beans you are to obtain. The beans are obtained in this manner: fill the 29-cu. in. container. Pour 3 cu. in. from it into the smaller container leaving 26 cu. in. in the large container. Again fill the 3-cu. in. container. Now 23 cu. in. remain in the large jar. Again fill the 3-cu. in. jar and the required 20 cu. in. are in the large container. When you are finished return the beans to the storage vessel. (Problem two is then presented.) This problem can be solved in the following manner. Fill the 59-cu. in. container and then empty a sufficient quantity into the 9-cu. in. container, leaving 50 cu. in. in the large container. Then fill the 5-cu. in. container, leaving 45 cu. in. Doing this once more will give you the solution, i.e., you will have 40 cu. in. of beans in the large container. This problem can *also* be solved by filling the 5-cu. in. container and emptying it into the 59-cu. in. container. If you do this seven times more you will have 40 cu. in. Do you understand? If so, here is the next problem."

Problems 2 through 9 can all be solved by a set procedure which, when put in algebraic form, would read *b-a-2c*. Problem 10, the test problem, can be solved either by the *b-a-2c* method or more directly by subtracting the *c* container from the *a* container. The performance of the *S*s on this problem tested the strength and rigidity of the established mental set.

The *S*s were divided into two main groups. Group M had a zero time interval between

TABLE 1

THE SERIES OF ARITHMETICAL PROBLEMS

Problem	Containers Given (in Cubic Inches)			To Get
	a	*b*	*c*	
Demonstration				
1	29	3		20
2	9	59	5	40
Training				
3	10	59	4	41
4	18	43	10	5
5	20	59	4	31
6	9	25	6	4
7	3	59	18	20
8	4	49	14	17
9	8	43	10	15
Test				
10	23	49	3	20

successive training problems while Group D had a 3-min. time interval between successive training problems. During this 3-min. time interval, the distributed *Ss* were occupied by rating humorous cartoons on a five-point scale of humorousness. This rating procedure was instituted immediately after the first problem.

In order to control the effects of a 3-min. interval prior to the test problem, half of each group had Problem 10 immediately follow Problem 9, while the remaining half had a 3-min. interval between problems. The various groups are designated in such a manner that the first capital letter indicates the condition of spacing during the *training trials* while the number following it reveals the time interval, in minutes, between the last training problem (Problem 9) and the test problem (Problem 10); Group D-0 had distributed conditions throughout the nine training problems but had Problem 10 following immediately upon the completion of Problem 9. Group D-3 had similar conditions except that 3 min. intervened between Problems 9 and 10.

A time limit of 5 min. was imposed upon any single problem. If, at the end of this period, no solution was forthcoming, the next problem was presented. Only the records of those *Ss* who solved at least six of the training problems (Problems 3 to 9) in the specific *b-a-2c* manner were included in the treatment of the results.

RESULTS

The performance of the experimental groups on Problem 10 reflected the relative influence massed and distributed practice had upon the learning of a mental set. For Problem 10 there were two major types of solutions: the direct solution (23–3) and the indirect solution (49–23–3–3). Another type of solution used by 14 of the 100 *Ss* involved filling the 49 unit container and from it filling the 23-unit container. Following these manipulations, 3 units of beans were removed from the 23-unit container. This type of solution was characterized as "indirect" since it involved unnecessary manipulations. Such a classification did not, however, affect the difference obtained between Groups D and M since an equal number of *Ss* ($N = 7$) in each group used this method of solving Problem 10.

As Table 2 indicates, there was a tendency for the *Ss* trained under massed conditions to acquire a stronger mental set than those trained under conditions of distribution when the effects of the training were measured in terms of performance on the test problem. One may reject the null hypothesis about the percentage differences between Groups D-3 and M-3, and between Groups D-0 and M-0, at the 37% ($t = .90$) and 1.4% ($t = 2.45$) levels, respectively. Since the shifting of spacing procedure for Groups D-0 and M-3 did not have any

TABLE 2

NUMBER AND PER CENT OF INDIRECT SOLUTIONS FOR PROBLEM 10
($N = 25$ each subgroup)

Group	Solutions		Group	Solutions		*t*
	No.	%		No.	%	
D-3	15	60	M-3	18	72	.90
D-0	11	44	M-0	19	76	2.45
D	26	52	M	37	74	2.33

TABLE 3

TIME IN SECONDS REQUIRED FOR SOLUTION OF THE TRAINING AND TEST PROBLEMS

Group	Training Problems (3–9)						Test Problem (10)					
	Indirect *Ss*		Direct *Ss*		*t*	*p*	Indirect *Ss*		Direct *Ss*		*t*	*p*
	Mean	SD	Mean	SD			Mean	SD	Mean	SD		
D-3	55.0	13.9	55.8	16.4	.12	.90	38.4	13.4	20.1	4.4	4.16	.01
D-0	45.1	11.1	61.6	26.6	2.01	.10	30.9	9.9	20.1	10.7	2.51	.02
M-0	41.2	10.1	54.8	13.6	1.94	.10	36.3	21.1	21.8	9.0	2.27	.05
M-3	45.2	17.1	47.7	10.7	.42	.70	35.4	16.6	17.4	5.5	3.83	.01

significant effect when compared to the performance of Groups D-3 and M-0, it appears justified, as well as advantageous, to combine the data of the two distributed and two massed subgroups. This difference between the combined massed and the combined distributed groups was significant at the 2% level ($t = 2.33$, $df = 98$).

Table 3 compares the time scores of the *Ss* who solved the test problem directly with those who solved it indirectly. The *Ss* in all subgroups were divided into those who solved Problem 10 directly or indirectly. The time scores for Problems 3–9 were obtained by averaging the median times for each *S*. It should be noted that no *significant* difference appears between the speed of solution *during the training trials* of the *Ss* who used the direct method during Problem 10 as compared with those who used the indirect method. In all four comparisons, however, the "direct" *Ss* tended to solve Problems 3–9 more slowly. The time data for Problem 10 are quite different. The difference between the time scores of the "direct" and "indirect" *Ss* on Problem 10 is highly significant. The combination of the probabilities yielded a chi-square significant well beyond the 1% level. In this case the habitual mode of responding was found to be less efficient.

DISCUSSION

The empirical question this experiment attempted to answer was rather simple. It sought to discover whether massed or distributed practice was more effective in the development of a mental set. The results of the test problem—which could either be solved with the set (indirect) method or by a simpler direct method—suggest that mental sets are developed to a stronger degree under conditions of massing as compared to conditions of distributed practice. These data appear at first glance to be inconsistent with the generalization that some form of positive distribution yields faster learning than massed practice.

What is the theoretical significance of these results? For some psychologists, the present results will merely confirm their belief in a hiatus existing between simple associative learning and problem solving behavior. They need not, consequently, attempt to formulate a theoretical system capable of integrating the phenomena of simple and complex learning situations. Other psychologists who are attempting to formulate more general behavior theories are required to

reconcile the findings from seemingly different psychological situations. The problem confronting this latter group is not merely to offer specific explanations of the present data, but rather to suggest a plausible explanation which would be capable of integrating the present results with those already reported within the area of distribution of practice. The present writers will suggest a possible reconciliation between the present data and the facts of distribution of practice.

Distributed practice has proven superior to massed practice in situations involving the acquisition of new response tendencies or the strengthening of very weak response tendencies (e.g., conditioned eyeblink response, mirror drawing, reverse alphabet printing, etc.). In the present experimental situation the task confronting *S* during the training problems is not the acquisition of a new response tendency, or the strengthening of a weak response tendency, since the response necessary for the correct solution (e.g., filling the middle container first) is one of the dominant response tendencies within the response repertoire of *S*. It appears that in the typical problem-solving situation, such as the one used in this experiment, *S* approaches the problem with many response tendencies markedly above threshold value —including the correct response tendency. The major task confronting *S* is to weaken the incorrect response tendencies so that the correct response will be evoked. During the training series, for example, *S* is required to eliminate any tendency to fill initially either the *a* or *c* container; i.e., these response tendencies must be weakened so that the "initial *b* response" gains ascendency. The problem-solving situation, therefore, is markedly different from that which exists in the conditioning situation. The primary task in the conditioning situation is to raise the desired response above threshold value. According to our analysis, the primary task in problem-solving situations is to make the correct response tendency dominant and unless the correct response is ascendent initially, this dominance of the correct response tendency will usually be achieved only by the active weakening of the incorrect tendencies.

The above analysis leads to what may be appropriately described as *an extinction hypothesis* of mental set. It is based upon the assumption that the learning of a mental set mainly reflects that portion of the learning process in which distributed practice is "inferior" to massed practice, viz., experimental extinction (3, 4).[1] According to our analysis the stronger mental set found in the massed group of the present experiment would be attributed to the assumption that the non-set responses of the massed group were weakened more rapidly and completely than those of the distributed group.[2] It would follow, therefore, that the "direct" response tendencies of the massed group would be weaker than those of the distributed group. This would lead, of course, to a greater per cent of indirect solutions given to the test problem by the massed group.

In closing, it may be appropriate to mention certain precautions that should be taken in evaluating the

[1] Sheffield (5) has recently reported relatively faster extinction under conditions of distributed extinction trials. There is reason to believe, as is indicated by Sheffield, that additional sets of variables, other than degree of spacing per se, produced these unusual results.

[2] The non-set responses, whether made implicitly or explicitly, would be weakened or extinguished because they would never be followed by the correct solution.

above extinction hypothesis of mental set. Essentially it states that factors which facilitate experimental extinction can also facilitate the development of mental sets. This formulation does not deny the influence of other variables (e.g., personality, perceptual orientation, etc.) on human thinking; it merely states that "extinction variables" are among the numerous variables functionally related to thinking behavior. The extinction hypothesis, in spite of its essential crudeness, is capable of generating additional tests of its validity. One would expect that in a concept formation situation a previously successful mode of response would be rejected more rapidly under conditions of massed practice. It would also be expected that the lower a set response is in a response hierarchy, the more effective would massed practice be for establishing the set. There are many additional deductions which can be made. Only through the systematic testing of these deductions can the extinction hypothesis of mental set and problem-solving behavior be adequately evaluated.

Summary

The purpose of the present investigation was to discover whether distributed practice is superior to massed practice in the learning of a mental set. Human *Ss* were given a series of concrete arithmetical problems which could be solved by one method. This set solution to all problems was developed during the training series by the technique of insuring its successful utilization. Half of the *Ss* were presented these training problems under massed conditions while the remainder had a 3-min. interval between successive problems. The strength of the set response was measured by a test problem which could be solved either with the set method or by a simpler non-set method. The results indicated that the mental set was learned to a stronger degree under conditions of massed practice. An "extinction hypothesis" of mental set is offered to explain these results and integrate them with the facts of distribution of practice.

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THE ACCURACY OF PREDICTION MOTION[1]

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Tracking, or the following of moving objects, has become a topic of lively interest among students of human behavior. Undoubtedly this interest originated in the many problems of operating fire-control equipment which were encountered in World War II. At first the problems tended to be practical or of immediate importance (5). Can tests be devised to select superior aerial gunners? What is the most efficient way to train trackers? However, it was not long before attempts were made to explain the nature of the processes underlying tracking. Little aid was provided by psychological theories. As Ellson points out, "Learning theory is too broad to be useful in this case since it has been concerned primarily with factors which determine the occurrence or nonoccurrence of a response and has not been extended to the details of response form . . ." (2, p. 10). Instead, the methods of operational analysis, used so successfully in conjunction with feedback or servo-mechanisms (including tracking machines), have furnished the framework for most of the theorizing. The formulations of Craik (1), Wiener (8), and Ellson (2) exemplify this approach. However, doubt has been raised by empirical investigation that human tracking behavior satisfies the conditions, such as linearity, required for operational analysis. Response patterns have been found by Searle and Taylor (7) which are pre-set; once started, they run their course regardless of new information or of their effect on error. Operational methods might be devised (if they do not already exist) to deal with such "cammed-in" behavior. Still, it is evident that there is much experimental work to be done on the characteristics of human tracking before it may be consigned to any general methodology or theory.

One of the most noteworthy characteristics of the human tracker is his ability to produce a smooth continuous path of motion. If he were a simple error-compensating servo, his long reaction time would doom him to a series of continued oscillations of error. Even while following a target moving at a slow constant rate he would be unable to reduce the amplitude of his initial oscillations (1). Trackers manage to avoid such erratic performance. One of the means by which they might do so is by continuously anticipating the motion of the target.[2]

A straightforward method for studying such *prediction motion* is the continuation of tracking motion after a target disappears from view. It is surprising that this simple technique has not been used in any of the considerable number of studies on kinesthesis. It is a natural extension of the study of discrimination of rates of motion of limbs. No investigations of this problem could be found. Something of the method was used in

[1] The undertaking of this study was assisted by a research grant provided by the University of California.

[2] Since submitting this article, the writer has encountered a similar analysis in an article by Dr. Harry Helson: Design of equipment and optimal human operation. *Amer. J. Psychol.*, 1949, 62, 473–479.

two studies, neither from the field of kinesthesis.

Travis and Dodge (7), in studying ocular behavior, required *Ss* to continue the visual following of a rod after it had moved briefly behind an obstruction. This behavior probably has an important relation to the tracking task in the sense of being an involuntary link in the chain of events. Unfortunately for present purposes, the data are analyzed in terms of the number of times there was smooth continuation of any sort. No measurement of rate or acceleration was described.

More recently the Army Air Forces (3) employed an animated motion picture task, called the Estimation of Velocity Test, CP205-B1, in which *S* saw an airplane fly into a cloud. He was required to judge, a short time later, where the airplane would be relative to an "anti-aircraft burst" which flashed on the cloud. The task is close to that needed for studying prediction motion, but no continuous record of the tracker's motion is obtainable. Further, the analysis was simply in terms of the number of "successes." One statement of present interest made in conjunction with the test is that *Ss* were generally able to detect errors of 1 in. on the screen. Since the rate of 6 in. per second was given as an example of target presentation, the average error of continuation would seem to be somewhat less than 20%.

Because of the absence of any previous studies which are directly relevant, the present study is necessarily an exploratory one. The method of the disappearing target was used with constant-rate, positively accelerated, and negatively accelerated motions. Interest was focused on such questions as these: Is prediction motion sufficiently accurate to be one of the mechanisms operating in tracking? Can acceleration as well as rate be maintained? Are there characteristics of prediction motion which are related to typical errors of tracking?

Method

Subjects.—The *Ss* were 20 members of the experimental psychology class at Santa Barbara College. Two additional *Ss* were used, but have been eliminated from consideration because of incomplete data. The group included 13 men and 7 women. Their ages ranged from 19 to 40 years. Most of the *Ss* were between 20 and 24 years of age. None of them were told the purpose of the experiment until its completion.

Apparatus.—The target presentation apparatus consisted of a motor-driven system of rollers which moved sheets of paper, 8½ in. wide, past a slit in the mask which was just above the paper. The slit was ¼ in. wide and 12 in. long. The paper speed was 8 mm./sec. Target paths were printed on the paper in the form of parallel lines, 5 mm. apart. The target, then, consisted of the 5 mm. space between the short portions of line which could be seen directly under the slit. It moved in the slit perpendicularly to the direction of movement of the paper. Target sheets were shielded from *S*'s view during the entire course of the experiment. At any instant he saw only the portion directly under the narrow slit.

Procedure.—The *S* stood so that the paper moved directly toward him. He was instructed to move a red pencil so that the point, which was held in the slit, was maintained as near the center of the target as possible. Further, he was told to continue moving the pencil after the target disappeared in such a way that it would continue to be on the target if it were still visible. The example given to all *Ss* was that of "following" the motion of an airplane which has flown behind a cloud. Some *Ss* were confused on the first few trials but after that the task became clear. In addition, *Ss* reported that the task was meaningful; they believed that there was one correct continuation path.

Three different patterns were used, all proceeding from left to right. In the following equations of motion, s designates distance in millimeters from the starting point, and t is the elapsed time from the start of the target motion:

$s = 8\ t$, the *zero pattern* (constant rate, zero acceleration)

$s = .4\ t^2$, the *plus pattern* (positive acceleration)

$s = 16\sqrt{5t}$, the *minus pattern* (negative acceleration)

On 30 of the 42 trials the patterns were given in *uncompleted* form, in which prediction motion was required. For the zero and plus patterns the presentation of the printed portion of the pattern lasted 10 sec.; for the minus pattern it lasted 5 sec. After the printed portion ended, the *S* had no further guidance. On the 12 other trials the *completed* pattern was given. The presentation time here was approximately 20 sec. for all patterns. Where uncompleted patterns were given they all ended at the same terminal rate of 8 mm./sec. Figure 1 shows the

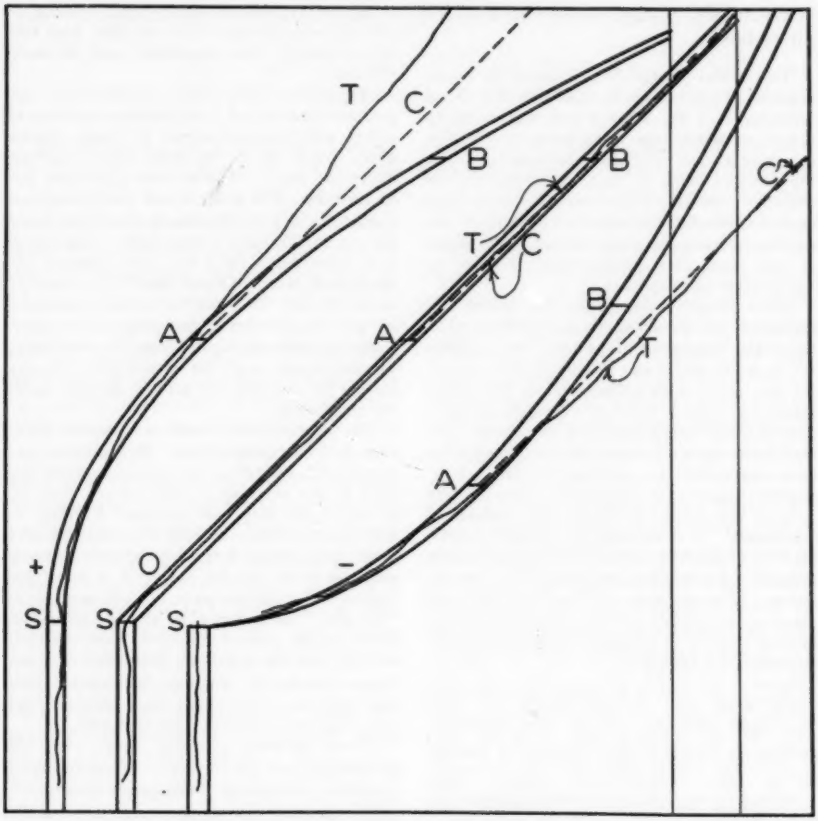

FIG. 1. Patterns and typical runs: **+**—the plus or positively accelerated pattern; **0**—the zero or constant-rate pattern; **−**—the minus or negatively accelerated pattern; **S**—start of pattern motion; **A**—end of guided (printed) portion of uncompleted patterns and start of six-second measuring period; **B**—end of six-second measuring period; **T**—lines traced by *S* No. 6, one run shown on each pattern (plus pattern: rate, 6.5 mm./sec.; accel. index, + .2 mm./sec.²; zero pattern: rate, 7.8 mm./sec.; accel. index, .0 mm./sec.²; minus pattern: rate, 8.5 mm./sec.; accel. index, − .4 mm./sec.²); **C**—dotted line, continuation of pattern at the 8 mm./sec. terminal rate.

three patterns in both their uncompleted and completed forms. *S*s continued their prediction motion when given uncompleted patterns until they crossed the right-hand limit or the end line.

The sequence of patterns on the 42 trials was the same for all *S*s. First there were 24 trials in which the patterns were given in uncompleted form; then there were 12 trials in which the completed patterns were given; finally there were six trials in which the uncompleted patterns were given. Within each of these groups of trials the three patterns occurred equally often and in scrambled order.

Measurements.—The tracings made by *S*s were read at the terminal point of the guided portion of the uncompleted patterns and at distances corresponding to intervals of 1 sec. for the 6 sec. following. Readings were made at the same points on the completed patterns. Accuracy was to the nearest millimeter. The period in which readings were made is indicated in Fig. 1.

Results

Continuation of Uncompleted Patterns

Over-all tendencies.—The rate of movement, in millimeters per second, was found for the entire 6 sec. following termination of the guided portion of the pattern for each run. The mean rate on the three patterns was then computed for each of the 20 *Ss* on the third through the eighth run on each pattern. The first two runs were omitted because some *Ss* were not yet accustomed to the general nature of the task.

The mean rates are presented in Table 1. The mean rate on the zero pattern was very close to the 8 mm./sec. "required" rate, the difference representing only 1% of that rate. However, on the plus pattern the mean rate was 33% *below* the value "required" by the completed equation of motion, and on the minus pattern the rate was 30% *above* the "required" value. The differences between the zero and plus patterns ($t = 4.06$; $r = +.24$) and the plus and minus patterns ($t = 4.91$; $r = +.32$) are significant beyond the 1% level; the difference between the zero and minus patterns is not significant ($t = 1.51$; $r = +.41$).

TABLE 1

MEAN CONTINUATION RATE OF MOVEMENT (IN MM./SEC.) AND RELIABILITY COEFFICIENTS FOR 6 SEC. FOLLOWING DISAPPEARANCE OF TARGET

(Mean of 6 trials for each of 20 *Ss*)

Acceleration Pattern	Required Rate	Obtained Rate		Odd-Even Reliability	
		Mean	*SD*	$r_{obt.}$	$r_{est.}$*
Zero	8.0	7.92	0.85	.74	.85
Plus	10.4	6.97	0.81	.82	.90
Minus	6.4	8.31	1.17	.84	.91

* Estimated by the Spearman-Brown formula.

TABLE 2

MEAN ACCELERATION INDEX (IN MM./SEC.²) AND RELIABILITY COEFFICIENTS FOR 6 SEC. FOLLOWING DISAPPEARANCE OF TARGET

(Mean of 6 trials for each of 20 *Ss*)

Acceleration Pattern	Required Index	Obtained Index		Odd-Even Reliability	
		Mean	*SD*	$r_{obt.}$	$r_{est.}$*
Zero	0	+.065	.30	.68	.81
Plus	+.8	+.105	.19	.67	.80
Minus	−.4	−.055	.25	.50	.67

* Estimated by the Spearman-Brown formula.

The reliability coefficients for these tasks are high, all being near .90 after correction by the Spearman-Brown formula to provide a coefficient for the entire six trials. The intercorrelations between continuation rate on the different patterns are all positive but moderate (.24, .41, and .32) and are not significant at the 5% level.

The mean continuation rates may be better comprehended by reference to Fig. 1. Tracings are shown of a typical *S* on runs which afforded rates near those of the group means. Especially striking is the low continuation rate on the plus pattern.

An *acceleration index* was obtained for each run by subtracting the rate of the first unguided second from that of the sixth unguided second, and then dividing this difference by six. It is recognized that this procedure does not provide a true average of the instantaneous accelerations. However, if *S* did make the "required" continuation, his index would be identical with that of the completed pattern. Consequently, it does provide a measure for studying the continuation of accelerations.

The analysis of acceleration indices is shown in Table 2. There was a significantly higher index on the plus pattern than on the minus pattern

($t = 3.48$, $p < .01$); further, the three patterns are in the proper sequence and the sign for the plus pattern is plus and that of the minus pattern is minus. On the other hand, it should be noted that the acceleration requirements of the completed patterns of motion are not approached by either the plus or minus patterns, the obtained means being nearer zero than the requirements of +0.8 and −0.4 mm./sec.[2]

The odd-even reliability coefficients were consistently lower for acceleration index than for continuation rate. Still, the values of .81, .80, and .67 (with the Spearman-Brown correction) for the zero, plus, and minus patterns, respectively, are indicative of consistent individual tendencies. Interestingly, the intercorrelations among the patterns were only slightly lower than the reliabilities ($r_{sp} = +.68$; $r_{sm} = +.80$; $r_{pm} = +.62$). This would seem to imply that the individual tendencies are fairly independent of previous pattern and that pattern accelerations are not maintained. The correlations between acceleration index and rate, running about .50, suggest that one of the determiners of rate is acceleration tendency.

A *time-in-run analysis* was made for each *S*. The mean rate of movement was determined separately for each of the 6 sec. following the end of the visible pattern and also for the last guided second. Figure 2 presents the over-all means for the 20 *S*s on each of those seconds. It is seen clearly that there were no appreciable differences in the last guided (−1) second. Large differences appear at the first unguided (+1) second and persist for the next 5 sec. The curves for the three patterns are markedly congruent. After the first unguided

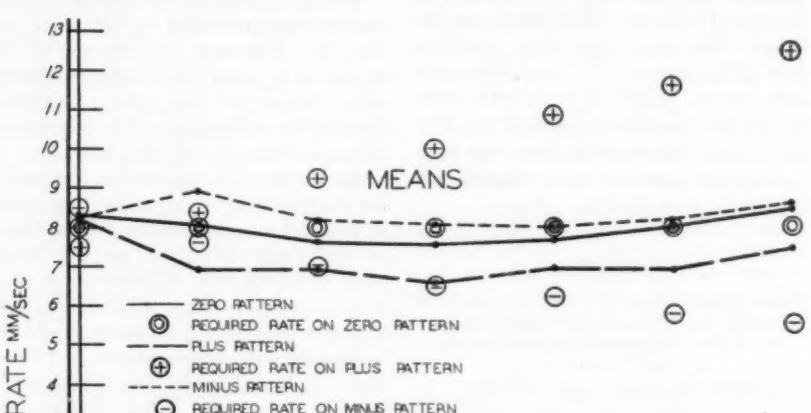

FIG. 2. Mean continuation rate and *SD* at each second, $N = 20$

second the rate drops for 2 or 3 sec. and then increases. The positive acceleration index for the plus pattern reflects an initial drop smaller than those for the other two patterns and also a somewhat greater rise. However, there is no continuous positive acceleration seen for the plus pattern nor continuous negative acceleration for the minus pattern. The divergence from the "required" rates shown by the appropriate symbols at each second emphasizes this point. The immediate difference in rate among the three patterns appearing even more strongly at the first unguided second than thereafter should be noted. It demonstrates that the method of studying prediction motion over a long (6-sec.) period provides results which are applicable to the short-time predictions, which very likely are of greater importance in actual tracking.

In the lower half of Fig. 2 are seen the *SD*'s of mean rates among *S*s for each second. As might be expected there was a large increase from the last guided second to the first unguided second. Also seen is a gradual rise in variability through the six unguided seconds. The increase is not great and nowhere is there a sharp break. Greatest intersubject variability throughout is found for the minus pattern. The zero and plus patterns are fairly close together.

The question whether differences in the *S*'s rate of movement at the very end of the guided portion of a pattern terminating at a given rate are predictive of continuation behavior was considered. That this is unlikely is seen in comparing the obviously small differences between the three patterns in the last guided second with the large and stable differences which develop within the next second. The problem was then dealt with by analyzing each pattern separately, correlating the mean last-guided-second rate for each *S* with his mean continuation rate for the subsequent 6-sec. unguided period. The three correlation coefficients were +.03, +.27, and +.03 for the zero, plus, and minus patterns respectively. Again, differences in previous guided rate do not predict differences in subsequent continuation rate.

Consistency and accuracy of rates.—For each of the three patterns the average deviation of each *S*'s six runs about his own mean rate was computed, and the mean of these 20 average deviations was determined. The values were .57 mm./sec. for the zero pattern, .64 mm./sec. for the plus pattern, and .86 mm./sec. for the minus pattern. There was little difference between the means of the zero and plus patterns ($t = 1.0$, $p > .05$). However, the mean average deviation on the minus pattern was significantly higher than that on the zero pattern ($t = 3.02$, $p < .01$) and that on the plus pattern ($t = 3.00$, $p < .01$).

Average error on the six runs of the zero pattern from the constant 8 mm./sec. rate was computed for each *S*. This was not done for the two other patterns because almost every run deviated from the "required" value in the same direction, making constant error practically identical with average error. Constant errors have already been described in the analysis of mean continuation rates. The mean average error on the zero pattern was .89 mm./sec. which amounts to 11.1% of the constant rate.

Inter-trial comparisons.—In Fig. 3 are shown the mean rate and the mean acceleration index on each trial. The first six trials indicated comprise the group used for all the foregoing analyses. Trials 7 and 8 occurred

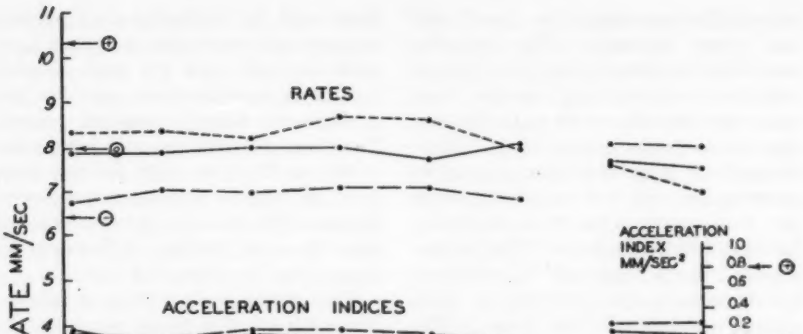

FIG. 3. Mean continuation rate and acceleration index on each trial, $N = 20$

after the *Ss* had experienced the completed patterns.

In the upper set of curves the mean continuation rates are shown. The values for the zero and plus patterns appear quite stable on the first six trials. Somewhat more variability is seen for the minus pattern, but it is difficult to make out a trend. Certainly there is consistency throughout the first six trials in the relative positions of the three curves. Marked changes occurred on the two trials after the *Ss* were acquainted with the whole patterns. The plus and minus patterns were forced in the direction of the "required" values but the corrections were far from sufficient. Interestingly enough, the performance on the zero pattern was poorer on the last two trials.

Mean acceleration index, shown in the lower set of curves, is also stable and the curves retain their relative positions quite well. Some movement toward the "required" accelerations is seen on Trials 7 and 8. That this was due to instances of proper rate-acceleration combinations was evident from examination of individual runs.

Prediction of Tracking Success

The same 6-sec. period used for analyzing the uncompleted patterns was employed for the 12 trials in which the completed patterns were given. Readings were taken at the same points 1 sec. apart. An average error was computed around the center of the target for each run. The statistical analysis of the four runs on each pattern is given in Table 3. Since the width of the target was 5 mm., the maximum average error which could be made while remaining within the target area is 2.5 mm. The actual values of .50, .81, and .62 mm. for the zero, plus, and minus patterns

respectively indicate that *Ss* made rather small errors in general. The reliabilities for the plus and minus patterns of .80 and .77 (corrected for six trials by the Spearman-Brown formula) are fairly high but the .45 value for the zero pattern indicates little consistency on that pattern.

Average error in tracking the completed pattern was correlated with continuation tendencies on the uncompleted patterns. That was done only for the plus and minus patterns because of the lack of reliability for the zero pattern average error. Mean continuation rate was correlated with average error because, as has been explained previously, it was a measure of constant error on the uncompleted plus and minus patterns. In the case of the minus pattern a high continuation rate was synonymous with a large constant error; consequently, predictability would be shown by a positive correlation. In the case of the plus pattern the correlation should be negative since errors were in the direction of being less than the "required" rate. As is seen in Table 3, neither correlation is significant. In order to find whether consistency on the uncompleted patterns was predictive of tracking error, average deviation on the uncompleted patterns was correlated with average error on the completed patterns. Again, the correlations are seen to be negligible. The intercorrelations among completed patterns in respect to average error were +.39 between the zero and plus patterns, +.27 between the zero and minus patterns, and +.33 between the plus and minus patterns. These are somewhat lower values than would be expected of satisfactory measures of tracking proficiency.

TABLE 3

MEAN AVERAGE ERROR AND RELIABILITY COEFFICIENTS ON COMPLETED PATTERNS AND CORRELATIONS WITH MEASURES ON UNCOMPLETED PATTERNS

(Mean of 4 trials for each of 20 *Ss*)

Acceleration Pattern	Mean Error	*SD*	Reliability		*r* with Uncompleted Pattern	
			$r_{obt.}$	$r_{est.}$*	Means	Av. Dev.
Zero	.50	.23	.29	.45		
Plus	.81	.34	.66	.80	−.16	−.04
Minus	.62	.21	.63	.77	−.004	−.02

* Estimated by the Spearman-Brown formula.

DISCUSSION

A steady rate of motion was maintained without much bias, the mean rate on all runs deviating 1% from the previous guided rate. The mean average error per run was about 11% of the guided rate. It may be shown that prediction motion having an 11% error of rate could provide a degree of accuracy in tracking such as might be expected in the present task. Assume, first, that the tracker makes intermittent corrections at half-second intervals. This appears reasonable on the basis of experimental evidence and has been suggested by several investigators (**1**, **4**). Next assume that he is exactly on target at a given instant of time. If the prediction-motion rate then initiated has an error of 11%, the maximum error reached before the tracker's next intermittent correction a half second later will amount to .44 mm. on the present constant-rate pattern. Even taking into account the more realistic case where the tracker starts from an incorrect position and is probably trying to incorporate some position correction into his prediction motion, the expected average error would not be far from the average error of .5 mm. found on the completed zero pattern. The more that prediction motion rather than position correction is uti-

lized, the smoother will be the path of motion.

Where the previous guided pattern has involved positive or negative acceleration, the constant error relative to the continuation of the accelerated path of motion is considerable. With prior positive acceleration, the prediction motion not only fails to continue the acceleration but is slower than the terminal guided rate. With negative acceleration the converse holds—the movement tends to be faster than the terminal rate. Two possibilities suggest themselves regarding the underlying state of affairs. Both involve the use of "stale" rates. One possibility is that *S* uses some single rate which has occurred before the end of the guided portion of the pattern. The other is that the previous rates, within some interval of time, have been averaged in a weighted function. The present data do not allow a discrimination between these hypotheses since only one positively accelerated pattern and one negatively accelerated pattern were employed.

Perhaps different results might have been obtained had the *S*s been told to continue accelerations as well as rates. Two points may be made in this respect. First, the great majority of *S*s did not "perceive" the acceleration, even after repeated exposure to it in the uncompleted patterns. Incidentally, there was some fear that learning would influence prediction motion on the later runs, making the six-trial analysis invalid. However, inter-trial consistency demonstrated that all six trials were comparable to one another. Hence, instructions to continue the acceleration would require *S*s to behave in a manner not characteristic of real-life situations where perception and motor response are part of the same package. The other point is that most *S*s who gained insight of the acceleration after seeing the completed patterns were not able to do much about it.[3] There is no "feeling" of acceleration as there is of rate. This immediately brings up the question of what the *S* makes of an accelerating target. Both the objective results and informal questioning provide the answer: "The target first moves at one rate and then changes to another." The smooth curve of acceleration is interpreted as a series of chords. The rate selected for continuation is the rate which is accepted as being constant at the end of guidance. This is not necessarily the actual rate of hand movement at that instant.

The effect of such selection is that of smoothing. It might seem that *S* is at a disadvantage in tracking tasks in not being able to maintain acceleration, but erratic changes in target behavior would less likely be upsetting when rate smoothing is employed. The accelerated patterns of the present experiment put rate smoothing at a disadvantage. However, where marked variations, such as changes in direction, are involved, more conservative predictions will result in smaller errors.

An explanation which has been suggested for the smoothness which is found in the performance of experienced trackers is that there is positive feedback so that the response tends to maintain itself (1). From this point of view, a close relation would be expected between differences in the movement at the end of guidance and and differences in prediction motion. This was not found. There was a

[3] The curious deterioration of performance on the constant-rate pattern which resulted from exposure to the completed pattern deserves some attention. This appears to be an instance in which both guidance and knowledge of results misinform the *S*. Perhaps it represents an overreaction against what *S* thought was the error of his ways.

lack of differentiation among patterns in last-second rates in the guided portion of the pattern. Also, last-guided-second rates and continuation rates among *Ss* on the same pattern were uncorrelated. In human tracking the relation between what the tracker does and how he analyzes or perceives the situation must be extremely complex.

The finding that continuation rates tended to remain constant over the 6-sec. measuring period is of importance in supporting the method of the present study. This period, rather than a briefer one, was selected in the interest of accuracy of measurement. However, from a theoretical point of view, the movement which occurs within a fraction of a second after the end of guidance has more relevance for tracking. Corrections probably occur about every half-second. It may be inferred from the constancy of rates that the initial tendencies are preserved over the 6-sec. period. As might have been expected, prediction motion was less consistent the longer the time interval since guidance. Still, changes were gradual and there was no point at which prediction broke down.

Prediction motion on the accelerated patterns followed very nearly the same kind of path of motion as did prediction motion on the constant-rate pattern. Still it was found that *Ss* had their individual acceleration tendencies. The high inter-pattern correlations of acceleration indices lends support to the view that acceleration is a characteristic of the person rather than of the pattern he is continuing. Perhaps acceleration tendency may be regarded as a time error in the perception of rate. A past rate may vary phenomenally over a period of time.

High reliabilities were characteristic of continuation rates and fairly high ones were obtained for acceleration indices. When it is remembered that only 36 sec. of performance went into each *S*'s mean continuation rate on a pattern, a reliability coefficient of .90 is impressive. This consistency of individual differences in prediction motion permits the hope that one of the important variables going into tracking proficiency has been identified. The ultimate test will be that of forecasting tracking performance.

In the present study the attempt to predict proficiency was not successful. Perhaps with more difficult patterns, giving more reliable tracking scores, a significant relation could be established between measures of prediction motion and tracking skill. The writer feels that there may be yet other reasons for the failure to predict performance on the completed patterns. Some *Ss* were obviously not striving for maximum accuracy on the completed patterns but were content to mark anywhere between the lines. This tendency was encouraged by the appearance of the target, the mechanics of the task, and by the early emphasis on prediction motion, where extreme accuracy was out of the question.

Mention should be made of one characteristic of tracking, in addition to smoothness, which ties in with the present findings. It has often been noted that gunners when attempting to aim squarely on target (as when using lead computing sights) tend to lag behind an approaching target and to aim ahead of a receding one. From the present findings on the prediction of accelerated motion this is exactly what would be expected. Prediction rates were too low on positively accelerated targets and too high on negatively accelerated targets.

Summary and Conclusions

Targets were provided for *Ss* to track by means of an apparatus which

moved sheets of paper upon which curves were printed. The target sheets were masked except for a narrow slit, causing the appearance of a short target moving lengthwise in the slit. Tracking was accomplished by moving a pencil in the slit so as to keep the point on target. The *S* was instructed to continue tracking after the target disappeared in the manner in which he would predict the motion of an airplane which has flown behind a cloud. Following are the principal findings and conclusions:

1. The mean rate of continuation of a constant rate deviated only about 1% from the required rate.

2. The mean average error of prediction motion on a constant-rate pattern was 11% of the required rate. This accuracy of prediction rate is sufficiently high to consider it a means by which smooth and accurate tracking could be accomplished.

3. Prediction of a positively accelerated motion is at a lower rate than the terminal guided rate; prediction of negatively accelerated motion is at a rate higher than the terminal guided rate. This reflects the operation of a rate-smoothing mechanism in tracking. Accelerations were generally not continued in prediction motion. There were consistent individual differences in acceleration of the continuation path but these did not depend upon the acceleration characteristics of the target. The use of a rate-smoothing rather than an acceleration-continuing mechanism may represent a conservative tendency in tracking which would be valuable in following targets with erratic paths of motion.

4. Individual differences in measures of prediction motion were reliable. Reliability of continuation rate was especially high.

5. Repeated exposure to the same segment of an accelerated pattern did not cause *S*s to learn to extend the acceleration. Exposure to the portion of the path which was later to be predicted did result in some instances of continuation of acceleration.

6. Differences in prediction motion could not be predicted from differences in the previous guided motion. That is interpreted as evidence against the positive-feedback explanation of smoothness of tracking.

7. The correlation between measures of prediction motion and tracking proficiency was negligible.

8. The tendency of gunners to lag on approaching targets and to lead on receding ones is in accord with the present findings on accelerated targets.

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THE METHOD OF COMPARISON APPLIED TO THE PROBLEM OF MEMORY CHANGE

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Irwin and Seidenfeld (6) published a study some years ago which seemed to open a new approach to the study of memory change and to tie it to the problem of time error as found in the usual psychophysical experiment. Their study was well conceived and logically planned on the basis of the known facts in these fields of study. The work on memory was inspired by the well-known studies of Wulf (12). The method of comparison was adapted from the psychophysical studies, and the method of equal stimuli from the work of Arons and Irwin (1) on lifted weights. At the time of the Irwin and Seidenfeld study the error in method in Wulf's study had not been pointed out. Unwittingly they included a modified version of it in their design.

Irwin and Seidenfeld presented their *Ss* with a series of six simple designs in the learning period. The identical designs (method of equal stimuli) were presented again after 3 min. with the strong inference that they were slightly different. At this second presentation 11 judgments were requested, two for each figure save one. The *Ss* were instructed to indicate on a prepared answer sheet whether the presented designs were greater or less than some designated characteristic of the original figure, e.g., "Is the gap in the circle greater or less?" Again after 10 min., and after seven days, the same *Ss* were presented with the same designs and asked the same questions. No equal judgments were allowed. They were warned to make the second and third judgments on the basis of the original experience and not to let the subsequent experience influence them, an assignment which was probably impossible to carry out.

At approximately the same time as the above publication, the present author published a study (3) in which the method of successive reproduction, as used by Wulf, was compared with the method of single reproduction. In repeated reproduction the same *Ss* make repeated reproductions of the designs observed in the learning period. In single reproduction, matched groups of *Ss* make single reproductions of the stimuli, a different group for each time interval. Wulf concluded on the basis of his study that there was a gradual growth toward a "better" figure with the passing of time instead of the usually reported dimming of the trace. He did not realize that the method of repeated reproduction favors a learning curve rather than a curve of forgetting. The results from the method of single reproduction clearly demonstrated the error of Wulf's method in this respect (3).

Like Wulf, Irwin and Seidenfeld assumed that they were measuring the fate of the trace from the original learning to the seven day test period, and that they were taking a sample of the course of the trace with the passing of time without disturbing it in the process. This is an invalid assumption. Since the *Ss* of Irwin and Seidenfeld saw the correct figure in each comparison period they carried over to the next comparison a review of the original stimulus and the effect of having made a false judgment (no equal judgment was allowed). All judgments beyond the 3-min. period were based upon new learning and one or two erroneous answers.

The most positive finding of Irwin and Seidenfeld was the high degree of consistency of the asymmetry of judgments: in 9 of the 11 characteristics, the preponderance of judgments at all time intervals was either above or below the 50% or chance level. (In Table 1 their results are shown in parentheses for ready comparison with our own.) They found little evidence for progressive change in the asymmetries as demanded by the Gestalt hypothesis. However they concluded that in part their results substantiate the Gestalt hypothesis and that the remainder are in no way inconsistent with it.

[1] The author is indebted to the following for assistance in collecting data for this research: Miss Maureen Rushmore—157 *Ss*, 1942–43; Miss Vilma Olsvary—126 *Ss*, 1947–48; Miss Rebecca Barker—164 *Ss*, 1948–49. Miss Barker also assisted in checking the results of the former workers and in bringing them all together in their present form.

Purpose of the Experiment

The purpose of the present experiment is to check the method of Irwin and Seidenfeld with particular reference to the validity of successive comparison, just as in the former paper (3) we tested Wulf's method of successive reproduction. It is possible that the method of successive comparison accounts for the consistent preponderance of judgments above or below the chance level, as revealed by Irwin and Seidenfeld. Our interest is more in method than in the results as such for it would seem that there is little need in again laying low the Gestalt theory of memory trace. Moreover the method of Irwin and Seidenfeld is still unchallenged in the literature, and other studies using their designs and methods have been published (10, 11). Even at this writing Wulf's method of successive reproduction is still being used despite the evidence against its validity (2). We are further interested in making certain refinements in the method as a whole, and in exploring further the relationship between memory trace and the time error.

Procedure

The six designs used in this experiment were photographic reproductions of those used by Irwin and Seidenfeld, and are shown in Fig. 1.

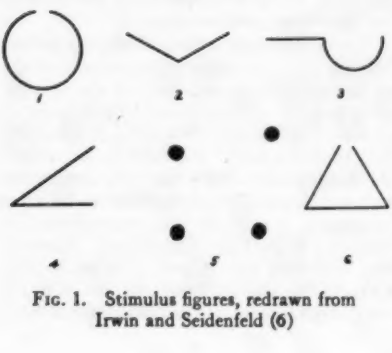

Fig. 1. Stimulus figures, redrawn from Irwin and Seidenfeld (6)

The critical change in procedure was the substitution of single comparison where Irwin and Seidenfeld had used successive comparison. We used three matched groups of *Ss*, one for each comparison period, where they used the same group of *Ss* for all three comparisons. There were other minor changes in procedure. Our designs were considerably larger as stimuli since we projected them on a screen where Irwin and Seidenfeld had exposed them in a stimulus box. The 5-sec. exposure time and the method of recording judgments—underlining one of two categories on a prepared answer sheet—were the same in both methods. However the answer sheets and spoken requests for judgments were different. On the answer sheet of Irwin and Seidenfeld, and in the spoken request for judgments, the greater judgment always came first. In order to rule out any position effect we made two answer sheets, staggering greater and less. Thus the group with answer sheet A was asked "Is the gap in the circle wider or narrower?" and the answer sheet had "wider" in t' first column and "narrower" in the second column. The group with answer sheet B was asked if the gap in the circle was narrower or wider and "narrower" appeared in the first column and "wider" in the second. Each form was used by approximately half of our *Ss* for each time interval.

Another minor change in the stimulus situation was also introduced. In some preliminary work we were disturbed by the reports of *Ss* that there was no difference in the designs which appeared in the learning period and the test period. In order to increase the illusion of a difference we had two sets of positive film made. The series for the learning period had a clearly visible A in the lower right-hand corner and the test series had a B in place of the A. Even so, many *Ss* insisted that there was no difference in the designs. This point will be discussed later in connection with a general criticism of the method.

Instructions to subjects.—The *E* read the following instructions before the learning period: "I am going to show you several different figures. I want you to observe them very carefully while they are exposed, so that if I show you some similar figures in the future you will be able to compare them with these. Remember, look at each figure as long as it is exposed, but do not write or draw anything or talk to your neighbor about it."

The record sheets having been handed out, *E* read the following instructions to *Ss* in the test or comparison period: "This is an experiment dealing with small differences; I am going to show you some figures more or less like those you have already seen. As I show you each

figure I shall ask you one or two questions about it. Each question can be answered by underlining the proper word on your answer sheet. You will see that there are two possibilities indicated on the answer sheet for each question; you must make a choice between them, and underline one of them no matter how hard it may be. If you are entirely undecided, please guess as well as you can, so as not to omit any answer."

The first figure, *identical* with the one previously shown save for the fact that it had the letter B in the lower right hand corner in place of the A, was then exposed. As it was exposed the following instructions were given: "Please compare this figure with the one like it which you were shown originally. Now underline in line 1 on your answer sheet the word which best answers the following question: Is the gap *wider* or *narrower* than the gap in the original figure? All right, now please indicate in line 2 the best answer to the question: Is this figure *larger* or *smaller* than the original figure?"

This process was carried out for the six figures and the 11 questions. Of course, the questions had to be changed around to conform to the differences in answer sheets A and B as described above.

Subjects.—A total of 447 *Ss* was tested: 153 after 3 min., 131 after 10 min., and 163 after 7 days. All *Ss* were female, and with few exceptions, college sophomores. The age range was 17 to 21 years. Irwin and Seidenfeld used both male and female *Ss*.

Results and Discussion

The most positive finding of Irwin and Seidenfeld in relation to the Gestalt theory of memory was the high degree of consistency of the asymmetry of judgments at the different time intervals. If the preponderance of judgments was above or below the 50% or chance level at 3 min., it tended to maintain that position in the subsequent tests at 10 min. and 7 days. Furthermore, Irwin and Rovner (7), in repeating the above experiment in part for the 3-min. comparison, found that the consistent direction of error was maintained although the degree of error varied a great deal for some of the questions. They explained this difference in degree as being due to the small number of cases, but an inspection of their table reveals no relationship between the size of their sample and the size of the discrepancy.

The present results do not confirm this consistency of asymmetry. Of the 11 characteristics, six of them are inconsistent in this respect (see Table 1). Of the five which are consistent in being all on the same side of the 50% line at all three time intervals, two of them, 6 and 9, are opposite those obtained by Irwin and Seidenfeld. Our results are more in line with Seidenfeld's (10) in this respect. Only one of his five series of judgments failed to cross the 50% line in repeated recognition. Also two of his five judgments are inconsistent with Irwin and Seidenfeld in the direction of the initial asymmetry at 3 min. Irwin and Seidenfeld also found some inconsistency in initial asymmetry when they broke up their large sample on the basis of distance from the stimulus (6, Table II).

The method of Irwin and Seidenfeld was followed in estimating the significance of the deviations from chance. The standard error of 50% was found by the formula $\sigma_p = \sqrt{pq/n}$. In both the present results and those of Irwin and Seidenfeld the σ_p is approximately 4%. Consequently it can be assumed that if the difference between the percentage of greater judgments and 50% is more than three times the σ_p, the asymmetry is significant. Irwin and Seidenfeld considered a difference of 2.5 σ_p as significant, but because of the unstable results secured by this method it was decided to use the more strict standard. For example, in the case of the size of the acute angle, both their results and ours show significant asymmetries at 3 min. but in the opposite direction. The results from three samples of *Ss*, tested in three

TABLE 1

PERCENTAGE OF "GREATER" JUDGMENTS FOR EACH CHARACTERISTIC FOR EACH TIME INTERVAL WITH THE METHOD OF SINGLE COMPARISON AND WITH THE METHOD OF REPEATED COMPARISON (IN PARENTHESES)

Quest. No.	Characteristic	Per Cent "Greater" Judgments			Critical Ratios		
		3 min.	10 min.	7 days	3 min.	10 min.	7 days
1	Width of gap (circle)	47* (72)**	57 (61)	44 (65)	0.7 (5.6)	1.7 (2.8)	1.5 (3.7)
10	Width of gap (triangle)	55 (61)	60 (56)	51 (55)	1.2 (2.8)	2.5 (1.4)	0.2 (1.3)
	Average for width (Quest. 1 & 10)	51.0 (66.5)	58.5 (58.5)	47.5 (60.0)			
9	Squareness (dot figure)	55 (47)	61 (39)	60 (35)	1.2 (0.8)	2.7 (2.8)	2.5 (3.8)
2	Area of circle	45 (56)	50 (60)	58 (57)	1.2 (1.6)	0.0 (2.5)	2.0 (1.7)
8	Area of square	48 (49)	53 (46)	72 (50)	0.5 (0.2)	0.7 (1.0)	5.5 (0.0)
11	Area of triangle	48 (43)	59 (30)	57 (39)	0.5 (1.7)	2.2 (4.9)	1.7 (2.8)
	Average for area (Quest. 2, 8, & 11)	47 (49)	54 (45)	62 (49)			
3	Size of angle (obtuse)	35 (66)	52 (65)	55 (62)	3.7 (4.1)	0.5 (3.7)	1.2 (2.9)
7	Size of angle (acute)	43 (51)	38 (41)	45 (44)	1.7 (0.2)	3.0 (2.3)	1.2 (1.6)
6	Length of short line (acute angle)	40 (50)	46 (62)	43 (58)	2.5 (0.0)	1.0 (2.7)	1.7 (2.0)
4	Length of straight line (curved figure)	27 (41)	24 (41)	25 (48)	5.7 (2.3)	6.5 (2.2)	6.2 (0.4)
5	Curvature of arc	87 (72)	77 (55)	67 (59)	9.2 (5.6)	6.7 (1.3)	4.2 (2.3)
	General average	48 (55)	52 (51)	52 (52)			

* The σ_p of 50% for all data is approximately 4%.
** Results in parentheses are those obtained by Irwin and Seidenfeld (6) under similar conditions but with repeated comparison.

different years, which are combined in the present report, showed very little agreement in the direction of asymmetries save for the judgments based upon the "dipper" figure.

Irwin and Seidenfeld concluded that three of their 11 characteristics afforded a direct test of Gestalt trace theory, and that their results could be interpreted as positive evidence for the theory. These three characteristics are the size of the two gaps, and the squareness of the off-square dot figure. According to Gestalt theory the percentage of greater judgments should increase with time in the case of the gaps, for in the trace the gap has been gradually closing. In the case of the dot figure the percentage of less square judgments should show a similar increase because the trace should be growing more square. Irwin and Seidenfeld found three significant asymmetries out of a

total of nine chances, and all the asymmetries in accordance with the theory. We find no significant asymmetries and only five of the nine with preponderance of judgments in the direction demanded by the theory. Neither set of results shows "growth" of the trace in the expected direction.

There are three figures in which comparisons of area are made. Out of the 18 different sets of judgments from the two sets of results, two are found to be significant asymmetries, one "greater" in our results and one "less" in Irwin and Seidenfeld's. Our average results for these three figures (see Table 1) are quite similar despite the differences in procedure. This is interesting since the area of our stimulus figures is much greater due to projection, thus favorable for bringing out differences in size trend according to Koffka's hypothesis (8). This research furnishes additional evidence that there is no consistent trend for size in the memory trace with the passing of time.

Form No. 3, the line and arc figure, accounts for six out of our total of nine significant asymmetries, and the only ones which appear to demand an explanation other than chance distribution. Our three subgroups, tested in three different years, one of them before the war and two after, show very close agreement in their judgments based upon this figure. In fact the judgments for this figure are the only ones in which our three subgroups show the consistency of preponderance of judgments which Irwin and Seidenfeld found to prevail so widely in their study. Unfortunately, we cannot compare our study directly with that of Irwin and Seidenfeld concerning the length of the short line, for we misunderstood their directions and asked our *Ss* to compare the short line in length with itself, whereas they apparently had asked for a comparison with the length of the arc of the circle, an entirely different comparison. This could account for the difference in our results for this comparison. The curvature of the arc can be directly compared, and where our experimental method is most like theirs, at the 3-min. period, we are in very close agreement. It is difficult to explain why we get definite asymmetries for this figure. It appears that some perceptual factor is responsible for the results but at the present writing we are unable to identify it.

In the light of the results as a whole it is apparent that the consistent preponderance of greater or less judgments reported by Irwin and Seidenfeld are not born out in our improved experimental design. Aside from the "dipper" figure, we find no substantial evidence for anything save a chance distribution of judgments. Certainly there is no evidence to substantiate the Gestalt hypothesis of memory trace, i.e., pregnance, closure, growth of the trace with the passing of time. Neither is there any substantial evidence for change in the size of the trace with the passing of time. Unfortunately our results are largely of negative value. There is little positive evidence concerning the nature of the trace and its relation to the negative time error.

On the surface the method of comparison would appear to be an excellent way of studying the memory trace and its relation to the time error in the psychophysical experiment. We have pointed out the weakness of *successive* comparison as used by Irwin and Seidenfeld. The same arguments are applicable to Seidenfeld's study (10) as shown by Hebb and Foord (5). It would appear that this method in its present form, despite the improve-

ments introduced, is of limited service in studying either the memory trace or the time error. The data secured by the method are quite unstable. There is little difference in response between the 3-min. comparison and the 7-day comparison. Real forgetting appears to be masked by the introduction of the stimulus figure in the test period, even though the inference is made that it is slightly different from the original figure. At the conclusion of the test period our *Ss* were asked to make introspections. The most frequent comments were: "no difference between the learning and the test designs" or "my answers were pure guess." The present method would appear to have some value in special problems where the stimulus is indefinite enough so that it cannot be readily identified, as in the case of memory for color (4). Another possibility is to use the method of comparison without the use of equal stimuli as Postman and Page (9) have done.

Summary and Conclusions

In this study we have attempted to improve the method of Irwin and Seidenfeld for studying memory change by the method of comparison. The chief improvement is the substitution of the method of single comparison for their method of successive comparison. Other minor improvements in design are also introduced. As a result of these improvements in method we find that the evidence of Irwin and Seidenfeld in favor of the Gestalt hypothesis of memory trace disappears. Save for one figure we find no consistent asymmetries. This one figure is not critical for the Gestalt hypothesis, and the asymmetry would appear to be due to a perceptual rather than to a memory factor. There is no evidence for the growth of the trace as concerns size of designs.

The present method of comparison as applied to memory change is criticized on the basis of the instability of results and the masking of true forgetting.

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WORD RECOGNITION AS A FUNCTION OF RETINAL LOCUS[1]

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Stimulus conditions may be altered in a variety of ways and yet in terms of the reaction produced the situations may be equivalent. One form of equivalence is demonstrated, for example, by man's ability to recognize an object in any visual field of sufficient acuity. Evidence of this kind indicates that the same response may be elicited by the stimulation of different sensory cells, and it has been generally concluded, as in "field theory" (3) and "equipotentiality" (4), that the perception must therefore depend on a pattern of excitation whose locus is unimportant. Opposed to this interpretation is the theory presented by Hebb (1) in which it is assumed that a particular perception depends on the action of particular neural cells, assembled slowly by the repeated stimulation of a specific receptor matrix. The proposal that separate parts of a receptor surface are individually trained leads to the view that equivalence is not spontaneous but is established by earlier learning. The necessary learning conditions are clearly present in vision since ordinarily retinal areas corresponding to fields of equal visual acuity receive the same amount of training. In reading English text, however, this may not be the case. The reader is persistently presented with the next word for recognition in the right field while he is still engaged with a word in central vision. The purpose of the present study was to determine whether this constitutes a selective training condition as would be suggested by the finding of non-equivalence between projections of the same word on different retinal loci. The results should provide evidence related to the opposing theories.

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Experiment I

A comparison was made of the recognition of English words in the left and right visual fields together with a control comparison in the upper and lower fields.

Procedure.—Forty-eight eight-letter words in two series of 24 each were presented tachistoscopically to 16 adult *Ss*. Each word, 2 in. long and ¼ in. high, was penned in lower case lettering on a white card. The same card was used for presenting the word in different visual fields. The tachistoscope was of a rotating type with a segment cut out of a weighted metal disk which revolved (through 150°) behind a vertical wooden screen in which there was an aperture 6 in. long and 3½ in. high. The stimulus card could be exposed in any one of several parts of the field 1½ in. behind the wooden screen, and ¾ in. behind the surface of the revolving disk. Exposure time was approximately .15 sec.

The field was illuminated by a shielded lamp in the midline, just above the aperture in the wooden screen and 3 in. in front of it. This arrangement lighted the lateral halves of the field equally, but provided higher lighting in the upper than in the lower half.

Each *S* was seated on a stool with his chin upon a fixed rest, his eyes approximately 24 in. from the stimulus card. Binocular viewing was employed.

For the first series of 24 words each *S* was instructed to fixate a small target in the center of the field. The stimulus words appeared in random order 1½ in. above or below, or 2 in. to the left or right. The measurements were made to the center of the word. For the second

24-word series fixation was directed in random sequence to one of four targets in the upper, lower, left, and right parts of the exposure field, with the word always appearing in the center. The distances from fixation to the center of the word were the same as before. The second method allowed *S* to anticipate the position of a word by predirected attention, permitting evaluation of the effect of this variable on recognition scores.

The choice of stimulus words was determined by the possibility that words containing commonly used prefixes and suffixes might have unequal effects in the left and right fields. For example, when a word with a common suffix is presented to the left of fixation, the part that provides the best cue for recognition falls at some distance from central vision, whereas it lies close to central vision when presented to the right. The exclusive use of such words might produce superior scores in the right field, and conversely for words with common prefixes. Stimuli were carefully selected to balance and permit detection of these effects if they existed. One group of words (e.g., precious, youthful) contained commonly used suffixes; another group (prohibit, transfer) contained commonly used prefixes; while a third group (broccoli, daffodil) had neither, or else was made up of two English words of which either might provide an equally good clue to the whole word (bluebird, woodpulp).

In each method of presentation the *S*s, words, and directions of words from the fixation point were arranged in a 4×4 latin square. Frequency of recognition in each field could then be determined apart from particular *S*s or particular stimulus words.

Each *S* was given a short practice session in which he became familiar with the conditions of the experiment.

The *S*s were observed carefully by the two *E*s and if eye movement occurred at the moment of exposure the response was discarded and a substitute word was added to the series.

Results.—One point was scored for a completely correct response, and one-half point for a response in which four or more letters of the word were reported in correct sequence. An analysis of the results revealed no unequal effects of the different word-types; in particular, recognition scores in the right visual field were as high for words containing common prefixes as for those containing common suffixes.

TABLE 1

RECOGNITION SCORES FOR WORDS PRESENTED ABOVE, BELOW, LEFT, AND RIGHT OF FIXATION, FOR EACH OF TWO METHODS SEPARATELY AND COMBINED (N = 16)

Direction from Fixation	Constant Fixation Point		Varied Fixation Point		Both Methods Combined	
	M	σ_M	*M*	σ_M	*M*	σ_M
Above	1.97*	.42	2.09	.44	4.06	.72
Below	3.97	.42	4.13	.41	8.10	.74
Left	1.59	.42	0.94	.24	2.53	.52
Right	3.31	.38	3.47	.43	6.78	.74

* Maximum possible mean score is 6.

Since no significant differences were found between the scores obtained in the two experimental procedures, they were combined. The result, presented in Table 1, is that recognition below the fixation point was nearly twice as good as above, and recognition to the right was more than two and a half times better than to the left. These differences between below and above, and right and left, are significant at better than the .01 level of confidence (t = 5.08 and 7.79, respectively, for 15 *df*). It is clear that exposures of the same word in the left and right visual fields are not equivalent stimulus situations. However, it is possible that several factors other than a selective retinal training may have been responsible, particularly since a recognition difference was also revealed in the control comparison. Alternative interpretations are considered in the following experiments.

EXPERIMENT II

It is unlikely that differences in visual acuity could account for the non-equivalence, since monocular acuity, in itself, is nearly symmetrical for the lateral fields (5, p. 484) and the

slight discrepancy that does exist is cancelled out in binocular vision. Even if all *Ss* had used only their right eyes, the small difference in acuity in favor of the temporal field could hardly have accounted for the marked superiority in recognition to the right of fixation.

However, several other explanations may be offered: *Ss* may have been attending selectively to the right perceptual field; an anisotropy of visual space (2, pp. 275–280) may result in a greater clarity or distinctiveness for patterns in the right field than in the left; the left occipital cortex may be "dominant" for vision.

To determine whether these or similar unidirectional factors could account for the results, a comparison of left and right field recognition of English words was made concurrently with that of Yiddish words, in which the letters run in the reverse order. If the explanations are correct, any differences in recognition clearly should be in the same direction for both languages.

Procedure.—Twenty-four English and 24 Yiddish words were presented tachistoscopically to 19 bilingual *Ss*, whose ages ranged from 12 to 24. The English words used for all *Ss* and the Yiddish words used for 10 *Ss* were five letters in length and were hand printed. Yiddish words for the remaining nine *Ss* were from three to five letters in length and were cut out of an elementary reader. The words, placed on small white cards, were exposed in random order 2 in. to the right or to the left of the central fixation target, so that *S* did not know on which side the next word would fall nor whether it would be English or Yiddish. Presentation was arranged with words, *Ss*, and visual fields in a 2×2 latin square.

Results.—Credit was given only for a completely correct response. As seen in Table 2, recognition was 40% greater for English words to the right than to the left and 25% greater for Yiddish words to the left than to the right of the fixation point.

TABLE 2

RECOGNITION SCORES FOR ENGLISH AND YIDDISH WORDS PRESENTED TO THE LEFT AND RIGHT OF FIXATION
(N = 19)

Language	Direction of Word from Fixation	M	σ_M
English	Left	4.13	.53
	Right	5.76	.58
Yiddish	Left	3.58	.52
	Right	2.87	.43

The English difference is highly significant statistically ($t = 3.54$, $p < .01$, 18 df), the Yiddish difference is not ($t = 1.78$, $p = <.10$, 18 df). This may be due to the fact that the *Ss*, whose native tongue was English, did not have a comparable reading facility in both languages, as indicated by their consistently lower recognition of Yiddish. Nevertheless, it is clear that whatever facilitated recognition of English in the right visual field did not similarly affect the recognition of Yiddish, and it may be concluded that unidirectional factors cannot account for the differential recognition.

EXPERIMENT III

An explanation consistent with the evidence from the preceding experiments might be offered on the assumption that the beginning of a word is more important than the ending as a cue for word perception. Thus, when an English word is placed in the right visual field, its initial letters lie closer to fixation, and hence in a field of greater visual acuity, than when the same word is placed in the left. In the case of a Yiddish word, the converse would be true.

If the assumption is correct the ending should be reported more frequently than the beginning in those responses in which only part of the

word is correctly perceived, since perception of the word-beginning would lead to a correct response. An analysis of the scores of the first experiment revealed only chance differences. Initial letters only were correctly reported 35 times, final letters 39 times. However, the point is too important to be dismissed on these data alone. Further evidence was obtained in a third experiment.

Procedure.—Twelve eight-letter words were presented tachistoscopically to 14 adult *Ss*. The fixation target coincided with the center of the word. The initial four letters of half the words and the final four letters of the remaining half were partly blurred by pencilling.

Results.—A score of 53 was obtained for words with the first half blurred and 50 for those with the second half blurred, demonstrating that in this situation the beginning of a word is no more essential than the ending for accurate perception.

Finally, it was found in Experiment IV, reported below, that words of four letters are recognized more accurately at certain positions in the right field than at corresponding positions in the left. It is unlikely that the initial two letters of a *four-letter* word are more important for its perception than the remainder. Furthermore, a word placed with its center 1½ in. to the right of fixation was perceived as frequently as a word with its center only 1 in. to the left. In this case the initial letters on the right were no closer to fixation than the initial letters on the left, and the whole word on the right was further from fixation.

From the several lines of evidence available it may be concluded that differences between recognition scores in the left and right fields cannot be due to the disproportionate significance of the first half as compared with the second half of the word.

Experiment IV

To determine the extent of the region in which differential recognition occurs, words were exposed at various distances from fixation.

Procedure.—A number of word positions were selected, one in the middle of the exposure field, and five on either side. These positions, as measured from fixation (midpoint in the field) to the center of the word, were displaced by ½ in. steps, equal to 1°11′ of the visual field. They will be designated as "center" and L_1 to L_5, and R_1 to R_5 for places in the left and right visual fields, respectively (L_1 and R_1 were next to the fixation point; L_5 was on the extreme left, R_5 on the extreme right).

Twenty-four four-letter words were presented tachistoscopically to 20 adult *Ss*. Each word, 1 in. long and ¼ in. high, was penned in lower case letters on a white card. The number of *Ss* tested at each position is reported in Fig. 1. The 24 words were equally divided among the positions at which each *S* was tested and a given word was presented to the entire group as frequently in a left field place as in the corresponding place on the right.

Results.—Only a completely correct response was scored. Accuracy of 98% was achieved for words placed at the center position. The drop in recognition on either side of the center is illustrated in Fig. 1.

Mean differences between scores at R_2 and L_2, and R_3 and L_3, are significant at the .01 and .05 levels of confidence, respectively ($t = 3.71$ and 2.16). All other right-left differences may be attributed to random errors of sampling.

The data indicate that the recognition differences are restricted to certain parts of the visual field. For these experimental conditions the region falls within the visual angle subtended by points at 1°11′ and 4°46′ from fixation (closing of the curves in Fig. 1). However, this finding would not preclude a more widespread effect for single letters or for words of more than four letters. In the first experiment, it should be

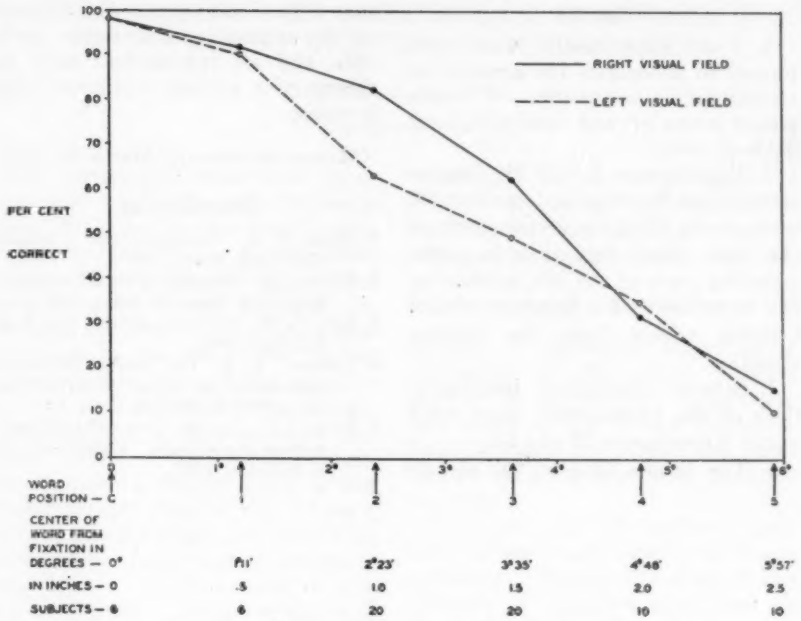

FIG. 1. Recognition curves for four-letter words placed at several positions in the right and left visual fields

noted, a significant difference was found between an eight-letter word placed with its center 2 in. to the right of fixation and the same word similarly displaced to the left.

CONCLUSIONS

It has been demonstrated that accuracy of word perception is largely dependent on the locus of retinal stimulation. Differences in visual acuity, a lateral cerebral "dominance," selective attention, the anisotropy of visual space, and the disproportionate significance of parts of a word, have been ruled out as explanations in control experiments. The results support the hypothesis that reading trains limited regions of the left hemiretina selectively. They are inconsistent with the theory of a *general* equipotentiality in vision since the learning involved in word recognition is not subject to complete transfer. Since there is an indication that English and Yiddish words are more accurately perceived in different visual fields, it appears that a more effective neural organization is developed in the corresponding cerebral hemispheres (left for English, right for Yiddish) as a result of training processes that are specific to the reading of those languages. It is suggested that a factor in the training may be the neural equivalent of a selective visual attention, although the data have indicated that when learning is complete this factor may no longer be operative.

Summary

1. Four experiments were performed to investigate the accuracy of tachistoscopic recognition of words placed in the left and right peripheral fields of vision.

2. Experiments I and IV demonstrated that *Ss* recognized significantly more words placed in certain parts of the right visual field than in corresponding parts of the left, confirming the hypothesis of a selective retinal training arising from the reading situation.

3. Several alternative interpretations of this phenomenon were ruled out in Experiments II and III.

4. The results support the theory that a particular perception depends on the excitation of particular nerve cells, and are inconsistent with the theory of a general equipotentiality in vision.

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SHAPE CONSTANCY: DEPENDENCE UPON ANGLE OF ROTATION; INDIVIDUAL DIFFERENCES[1]

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The perceptual constancies have been observed and discussed for many years, but have become best known and quantitatively investigated since the rise of Gestalt psychology. These phenomena have been described by Thouless (8) as cases of "phenomenal regression to the real," the phrase indicating that the apparent object is a compromise between the object considered as a stimulus and the "real" nature of the object. When, for example, a circular plate in the frontal-parallel plane is rotated on a vertical axis the retinal stimulus is an ellipse which, in perception, regresses towards the "real" nature of the object (a circle). Thus the shape of the *perceived* object is neither a circle nor an ellipse (like the retinal stimulus), but is somewhere between these two.

An index of the degree of regression, or constancy, has been proposed by Brunswik (1). In the typical shape constancy experiment a circle or a square is rotated on an axis through its center and *S* is asked to indicate what ellipse or what rectangle has the same apparent shape. The *E* can then measure the apparent shape of the object, the "real" nature of the object, and the nature of the object considered as a stimulus. (In this paper, "stimulus" will mean the image of the object, when projected upon a frontal-parallel plane passing through the axis of rotation. This "stimulus" is the determiner of Koffka's "proximal stimulus.") If these are designated as a, r, and s, respectively, the index of constancy is given by $\frac{a-s}{r-s}$ or, in verbal terms, the amount of regression stated as a proportion of the total possible amount of regression. Woodworth (11) refers to this as the Brunswik Ratio; if the logarithms of the numbers are used it becomes the Thouless ratio (8).

Brunswik and his students have investigated many aspects of shape constancy. Eissler (3) studied the influence of objective conditions on shape constancy. The data on six sophisticated *S*s showed that as the angle of rotation of the object increased the Brunswik Ratio decreased. Eissler suggested an explanatory concept (to be discussed later) but did not elaborate on the subject. Later findings of Sheehan (7) supported the results of Eissler's study, although one of the three points in her curve represented over-constancy (regression to, and beyond the real). A study by Moore (6) showed a lack of relationship between Brunswik Ratio and angle of rotation over most of the range studied. Thouless (8) obtained data on one *S* giving some indication of the relationship found by Eissler, but showing no change over part of the range.

The primary purpose of the present experiment was to verify and amplify Eissler's findings with naive *S*s and to lay the foundation for some analytical research on the phenomenon.

[1] The treatment of the data of this experiment was carried out during a summer research appointment granted to the author by the University Research Council of the University of Missouri.

A secondary purpose was to add to the information on individual differences and individual consistency in degree of shape constancy. Studies on the latter aspect have been carried out by Sheehan (7) and Thouless (10).

In view of these purposes, the general plan was to use a moderately large group of *S*s and, for each, to measure the Brunswik Ratio under four conditions involving different angles of rotation.

Method

Apparatus.—A sketch of the apparatus is given in Fig. 1. The *S* viewed, on his left, the variable stimulus (a square) which he was able to rotate by turning the small crank immediately in front of him; on his right was the standard stimulus. At the left of the apparatus was a shield hiding *E* and his materials; a similar shield was placed on the right for symmetry.

The variable stimulus was a square plate 5 in. on a side. The standard stimuli were rectangles; all were 5 in. high and the widths (of standard stimuli A, B, C, and D, respectively) were 4.75, 4.25, 3.75, and 3.25 in. All stimuli were mounted on dowels .75 in. in diameter. The distance between the standard and variable stimuli (center to center) was 24 in. and they were 5 in. in front of the background, a cream-colored plaster wall. The stimuli were painted a dull black; the dowels and the rest of the apparatus were painted a neutral gray. Illumination was provided by a large, high skylight.

The *S* sat in a chair which was moved to a fixed position. All *S*s were instructed to sit erect and lean against the back of the chair, but no other restriction or placement of head position was attempted. The distance from the the eyes of *S* to the line between stimuli was approximately 60 in.

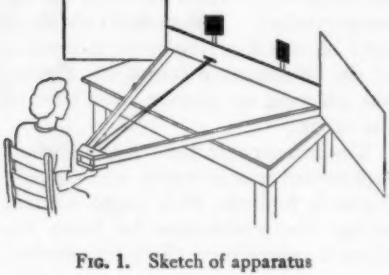

Fig. 1. Sketch of apparatus

The standard stimulus was in the plane at right angles to *S*'s line of vision when fixating on it. Likewise, 0° for the variable stimulus was the position in which it was at right angles to *S*'s line of vision when fixating on it. A pointer on the dowel carrying the variable stimulus moved over a fixed dial and indicated the position of the variable stimulus in degrees from this zero point. One complete turn of *S*'s crank rotated the stimulus approximately 1.5°.

Subjects.—The 50 volunteer *S*s were university undergraduate students ranging in age from 18 to 28 years. Only one was known to have a serious visual defect—a hole in the iris of one eye, in addition to a normal pupil. His results showed high degrees of constancy. Four *S*s wore corrective lenses at all times and 16 wore them for reading only.

Procedure.—On each trial the task of *S* was to rotate the variable stimulus (by turning the crank) until it appeared to be equal in shape and width to the standard stimulus. The *S*s were allowed to rotate the stimulus at will until they were satisfied with their settings.

Each *S* served for two 50-min. sessions, usually a week apart, though for seven *S*s the interval was only 3 days and for five it ranged from 15 to 29 days. At the beginning of the first session the nature of the task was explained and *S* made one trial match for each standard stimulus. Ninety-six settings were then obtained in 16 series of six each. The six judgments in each series were all on the same standard stimulus. The order of standard stimuli in the successive series was as follows: ABCD, CBDA, ADBC, DCBA. The order of the first four series was chosen so as to progress from the easier to the more difficult judgments. In the second session, 16 additional series were obtained in the same order as in the first session, but there were seven settings in each series.

The *E* set the variable stimulus at a predetermined position before each trial. Factors such as nearness of starting position, direction of turn, and final position (left edge of variable stimulus in front of or behind the frontal-parallel plane) were equated.

Measures.—The *E* recorded each setting in terms of angle of rotation from the frontal-parallel plane. Each of these settings was then changed into a measure of the object considered as a stimulus (as previously defined). For example, when the 5-in. square was turned 30°, its width as an image in the frontal-parallel plane passing through the axis of rotation was 4.33 in. In computing the Brunswik Ratio (BR) the various measures of the width of the

TABLE 1

BRUNSWIK RATIOS OF MEAN SETTINGS FOR THE STANDARD STIMULI IN EACH SERIES AND EACH SESSION

S_s	Session 1					Session 2				
	Series				All	Series				All
	1	2	3	4		1	2	3	4	
A	.79	.76	.79	.75	.77	.77	.77	.74	.73	.75
B	.65	.60	.61	.60	.61	.62	.60	.58	.56	.59
C	.50	.52	.51	.48	.50	.51	.47	.48	.48	.48
D	.44	.41	.39	.41	.42	.39	.41	.40	.41	.41

object were taken as indicators of its shape. The three measures all related to the *variable* stimulus. At 30° the stimulus nature of the object is given by the figure 4.33 in., the object nature is 5 in. (the dimension of the square plate), and the apparent nature is given by the width of the standard stimulus to which it has been matched.

All BR's to be presented were computed either from group mean widths or from the mean of the settings of one *S* under a certain condition. In other words, the *x* values (stimulus widths of the variable) were averaged and the BR was computed for the mean stimulus width. BR's were never averaged. To use examples in Table 1, the BR of .60 for the second series on standard stimulus B was obtained by finding, for each *S*, the mean setting on that series, then finding the mean of the individual means, then changing this to a BR. Ratios under the column labelled "all" were obtained by finding, for each *S*, the mean of all settings on the indicated standard stimulus, getting the mean of the individual means, and computing the ratio.

RESULTS

Angle of Rotation

A clear-cut relationship between BR and angle of rotation was found. Table 1 shows the BR's by standard stimulus, by series, and by session. In Session 1, for example, all the settings for standard stimulus A gave a BR of .77 while all those for standard stimulus D gave a BR of .42. The widest of the standard stimuli was A, and the narrowest was B, so these results mean that as the angle of rotation (of the variable stimulus) increased the BR decreased. The results are plotted in these terms in Fig. 2. The angles at which the points are plotted are those corresponding to the settings for mean widths. The nature of the relationship is very much the same in Session 1 and Session 2. Adjacent points on each curve differ with a statistical significance below the .001 level. This relationship can be found consistently in each series in each session.

The inter-individual variability of the mean settings also changed with standard stimulus or angle of rotation, the *SD* tending to increase as the latter increased. In Session 1, the *SD*'s of the mean settings ranged from .62 for standard stimulus A to .86 for standard stimulus D; in Session 2 they ranged from .62 to .74 inches (see Table 2). These are *SD*'s of mean stimulus widths (not BR's).

The differences and significance of differences between selected pairs of *SD*'s within sessions are given in Table 3. In general, the *SD*'s for A and B differ significantly from those for C and D in Session 1, but in Session 2 they differ only at the .10 level of significance.

The variability of BR's changes little with angle of rotation. It is given by the *Q*'s of the distributions of BR's for the two sessions. These

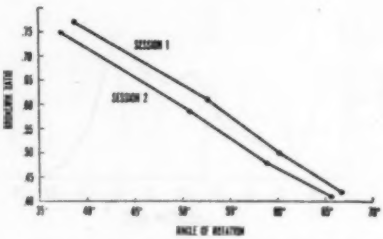

FIG. 2. Brunswik Ratio as a function of angle of rotation

TABLE 2

SD's of Mean Settings for the Standard Stimuli in Each Series and Each Session

S_s	Session 1					Session 2				
	Series				All	Series				All
	1	2	3	4		1	2	3	4	
A	.72	.67	.71	.68	.62	.76	.67	.61	.62	.62
B	.98	.79	.83	.83	.77	.80	.71	.73	.77	.68
C	1.0	.74	.82	.88	.83	.81	.75	.80	.76	.76
D	.97	.86	.95	.89	.86	.79	.78	.72	.81	.74

TABLE 3

Significance of Differences between Selected Pairs of *SD*'s

S_s	Session 1			Session 2		
	Diff.	$\sigma_{diff.}$	t	Diff.	$\sigma_{diff.}$	t
B–A	.15	.049	3.07**	...	...	...
C–A	.21	.064	3.27**	.14	.064	2.20*
D–A	.24	.071	3.37**	.12	.065	1.86
C–B	.06	.036	1.68	.08	.041	1.97
D–B	.09	.040	2.23*	.06	.039	1.72

* $.01 < p < .05$.
** $.001 < p < .01$.

values are 11.6, 11.5, 12.5, and 12.6 for standard stimuli A, B, C, and D respectively. Degree of constancy, as distinguished from apparent width, does not seem to become more variable as angle of rotation increases.

Individual Differences

For each *S* the mean of all trials with each standard stimulus was computed and these means were turned into BR's. The distributions of these ratios are shown in Fig. 3. The vertical lines mark the quartile points. The BR's of one *S* have not been plotted in curves C and D because of their extreme values. They are −.30 and −.38 for standard stimuli C and D, respectively. None of the curves approximates a normal distribution; curve D is platykurtic and curves A, B, and C are skewed to the left. This skew would have been reduced somewhat if Thouless ratios had been used instead of BR's. The

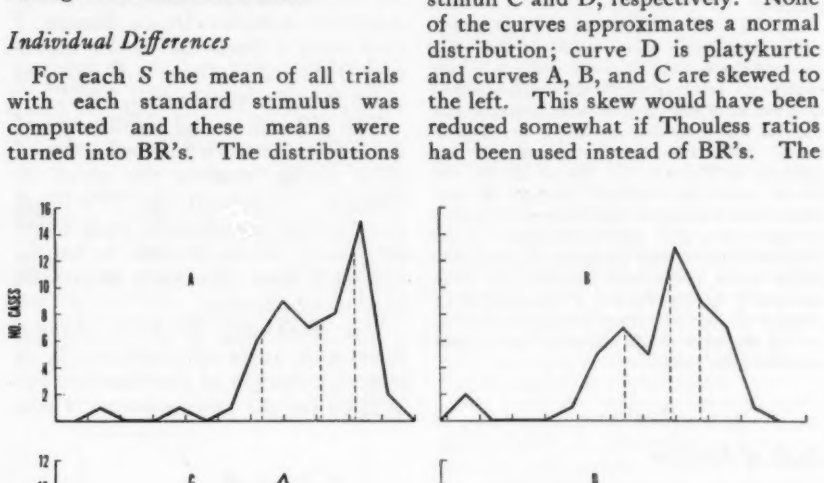

Fig. 3. Distributions of the Brunswik Ratios for the four standard stimuli. The vertical lines mark the quartiles. One case is not plotted in distributions C and D (see text).

curves show a remarkably wide range of individual differences. Degrees of constancy are generally high, although for standard stimuli C and D there are sizable minorities in the region below .25.

The consistency of the *Ss* in relative degrees of constancy is indicated by the correlations among the mean settings for the various stimuli and sessions. These Pearson product-moment correlations are given in Table 4. Most of the correlations are .88 or higher, which seems to indicate a reliable measure and considerable individual consistency. When considered in conjunction with the distributions in Fig. 3, it is clear that some *Ss* show consistently high degrees of constancy in this task, and some show consistently low degrees of constancy.

Practice Effects

Indications of practice or fatigue effects on constancy within and between sessions can be found in the data of Table 1. In both sessions the BR's tended to be lower in Series 4 than in Series 1. The differences are small, the largest being .06, but all but one are in the direction stated. In Session 1, for three standard stimuli, the BR's also decrease from Series 1 to Series 2. Session-to-session comparisons show a slight decrease in BR for the "All" columns and for Series 1 columns. The significance of these differences (when computed from the differences in mean settings) is given in Table 5. The differences within sessions are larger and more nearly significant than those between sessions.

TABLE 4

INTERCORRELATIONS AMONG MEAN SETTINGS FOR THE STANDARD STIMULI WITHIN SESSIONS AND BETWEEN SESSIONS

S_s	Within Session 1			Within Session 2			Between Sessions
	B	C	D	B	C	D	
A	.88	.70	.76	.73	.77	.75	.94
B		.95	.94		.92	.94	.88
C			.98			.88	.88
D							.92

TABLE 5

t-VALUES OF DIFFERENCES BETWEEN MEAN SETTINGS IN DIFFERENT SERIES

Difference***	Standard Stimulus			
	A	B	C	D
1–1 and 1–2	2.03*	4.59**	—	3.08**
1–1 and 1–4	2.31*	4.04**	2.29*	2.98**
2–1 and 2–4	1.98	3.63**	3.14**	—
1–all, 2–all	1.50	2.01*	1.83	.63
1–1 and 2–1	1.39	2.24*	—	4.19**

* Significant at the .05 level.
** Significant at the .01 level or better.
*** The number before the dash indicates the session; the number or word after the dash indicates the series, for that standard stimulus, within the session.

Table 1 suggests that the decrease in BR may take place chiefly between the first and second series in Session 1. The three differences are significant at the .05, .01, and .001 levels of confidence. If this is the case, it is illustrated by the course of the BR's for the 24 trials with standard stimulus B. These are shown in Fig. 4.

Practice effects with regard to inter-individual variability are suggested

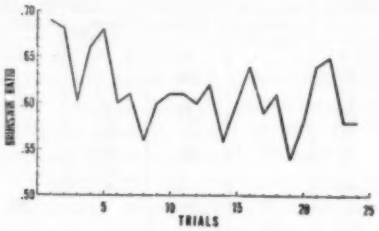

FIG. 4. Brunswik Ratios for the 24 trials on standard stimulus B in Session 1

by the data of Table 2. From Session 1 to Session 2, the *SD*'s of the distributions of individual means decrease for standard stimuli B, C, and D. These differences are significant at the .10, .20, and .02 levels of confidence, respectively. A trend towards decreasing *SD*'s within the sessions can be seen by comparing Series 1 and 4 in each session. It should be remembered that these are *SD*'s of mean stimulus widths.

Discussion

Angle of Rotation

The Index of Constancy.—The basic finding of the decrease in constancy with increasing angle of rotation confirms the results of Eissler (3) and Sheehan (7) and raises some questions concerning the results of Thouless (8) and Moore (6). The results of these four investigators are shown in Table 6. BR's were computed from Moore's data (for one stimulus object, a 4-in. circle); the other ratios were given by the authors.

In degree of constancy found and in the nature of the function, the results of this experiment are most similar to Eissler's. In his experiment, like this one, the object was rotated on a vertical axis. A difference was that in Eissler's experiment the rotated object (a circle) was the standard stimulus and the elliptical stimulus in the frontal-parallel plane was the variable.

Moore's results are most contradictory to those of the present study. Over the range from 25° to 40° no significant change in constancy was shown and the BR's were relatively low. These results may be related to two conditions in his experiment: the rotation of the stimulus on a horizontal axis (minimizing cues from binocular disparity) and the use of a low level of illumination, highly diffused from a single source.

The results of Thouless are of interest although only one *S* was used. Over the range from 30° to 65° results were similar to those of this study although degrees of constancy were low, again probably due to the rotation of the stimulus on a horizontal axis. Over the range from 7° to 30° he found no change in constancy.

Sheehan's data are similar to those of this experiment, but the fact that one of the three ratios shows considerable "over-constancy" is somewhat puzzling. She used a square plate with the axis of rotation through a diagonal placed in the horizontal plane.

TABLE 6

Results of Previous Experiments on Constancy as a Function of Angle of Rotation

Angle in Deg.	Eissler $N=6$ Brunswik Ratio	Thouless $N=1$ Thouless Ratio	Moore $N=6$ Brunswik Ratio	Sheehan $N=25$ Thouless Ratio
7		.28		
10		.41		
15				1.3
20		.33	.58	
25			.51	
30	.93	.32	.48	
35			.47	
40			.47	
45	.77	.16		.83
60	.69			
65		.10		
75	.54			.71

It seems likely, considering the results of Eissler, the trend in Sheehan's data, and the data of the present experiment, that in the usual shape constancy situation the index of constancy decreases as angle of rotation increases. Koffka (5) accepted this as true and attempted to explain Eissler's results. He assumed that (a) the non-normal orientation (rotation) of the object sets up a force tending to produce constancy, (b) this force does not increase in proportion to the rotation, (c) the distorted image sets up a force resisting constancy, and (d) this force increases more rapidly than angle of rotation. From these assumptions it logically follows that the degree of constancy will decrease as angle of rotation increases, because the force resisting constancy grows more rapidly than the force producing constancy. Assumptions (b) and (d) can be considered as restatements of the data

TABLE 7

QUANTITIES RELATING TO "TRANSFORMATION"

Angle	Constants a	Obtained		Theoretical*	
		$a-s$	$\frac{a-s}{s}$	$a-s$	$\frac{a-s}{s}$
38°	4.75	.81	.21	.81	.21
52°	4.25	1.15	.37	1.44	.46
60°	3.75	1.22	.48	1.88	.74
66°	3.25	1.21	.59	2.25	1.10

* Values necessary for a constant BR of .76.

in terms of assumptions (a) and (c), thus the latter two assumptions need to be tested.

Eissler does not attempt a comprehensive explanation of this finding, but he does emphasize that although constancy is decreasing, the "work of transformation" (2, 3) is increasing. This term is defined as $\frac{a-s}{s}$ (see p. 49 for definition of symbols), or regression stated as a proportion of the stimulus (image). This quantity, for the data of the present experiment, is shown in column four of Table 7. As in Eissler's experiment, although the BR is decreasing, this quantity is increasing (from .21 to .59). The use of this term indicates that Eissler considers regression *stated as a proportion of the stimulus* to be a basic measure. To the present writer it seems that the simpler quantity, $a-s$, may be a more fundamental and meaningful measure. (The total situation or the "real" object may be the parameter.) This quantity is shown in the third column of Table 7 and the values run from .81 to 1.21 (amount of regression in inches). Neither the values in the $\frac{a-s}{s}$ column nor their rate of change seems very meaningful, whereas the figures in the $a-s$ column show an asymptotic function, which seems to have theoretical implications: that as the cues to the "non-normal" orientation become stronger, more and more regression takes place, up to a limit set by the nature of the organism. In these data that limit is approximated by the number 1.22.

Whether one stresses $\frac{a-s}{s}$ or $a-s$, the index of constancy should be expected to decrease with increasing angles of rotation. If it remained the same both of these quantities, particularly $\frac{a-s}{s}$, would increase at a rapid rate with increasing angle of rotation. What these quantities would have been in this experiment if the BR had been constant at .76 through the four angles of rotation is shown in the last two columns of Table 7. It seems obvious that such increases in absolute or relative regression could hardly be expected.

To summarize: the decrease in the index of constancy with increasing angle of rotation seems to be some resultant of (a) the stronger cues with the increasing discrepancy between the stimulus nature and the "real" nature of the object, (b) a limit, set by the nature of the organism, on the amount of regression in a given situation, and (c) an asymptotic approach to this limit. By reason of the mathematical nature of the index, as partly illustrated by the last columns of Table 7, this approach to the limit results in a decreasing constancy ratio with increasing rotation of the object. Such a view obviously leaves many aspects of the process to be explained in detail.

Variability.—It was found that the variability of the *stimulus* measures (the width of the plate in the frontal-parallel plane) was greater for the large angles of rotation than for the

small, but that there was no apparent change in the variability of the BR's with angle of rotation. The nature of the apparatus and procedure may have contributed to the first finding. A given manipulation of the crank gave more change to the stimulus width at some angles than others: when the plate was at 10°, rotation 1° either way changed the stimulus width by approximately .015 in.; when the plate was at 80°, rotation 1° changed its width by approximately .08 in. Thus, a given motor error in crank position would mean greater variability at the large angles.

From a perceptual standpoint, this variability of settings means variation in *apparent width*. Perhaps it is to be expected that with greater opposition between stimulus factors, or greater discrepancy between "real" and stimulus objects, more unstable perceptions and greater variability would result. On the other hand, if amount of regression is approaching a limit, one might expect variability to *decrease*. If both these factors were operating, the former must have been the more important. The *Ss* reported the judgments at the larger angles of rotation to be the more difficult.

Individual Differences

The different shapes of the four distribution curves in Fig. 3 indicate that perhaps no single curve can represent the distribution of shape constancy judgments. The curve for stimulus B most nearly resembles the one curve shown by Thouless (10). Sheehan presents two curves (for 45° and 75° of rotation), one of which is unimodal, the other bimodal. The differences among these curves, including those of this experiment, suggest that the situations in which shape constancy is demonstrated are complex and the effects of the variables are not understood.

One variable which is probably not of major importance is that of intellectual and psychological sophistication of the *Ss*. The large individual differences in this experiment compared to the moderate differences between the present one and Eissler's lead to this conclusion.

The wide individual differences may have been related to uncontrolled differences in attitudes. The influence of attitudes has been studied by Klimpfinger (4) and Moore (6). It is also possible that individual differences in some type of previous perceptual experience were of primary importance.

There have been some indications in the literature (10) of intercorrelations between different kinds of constancy, such as size and shape constancy. The findings of this experiment are more limited, but the high intercorrelations between measures indicate that the degree of shape constancy shown was apparently a characteristic of the individual, perhaps depending upon rather basic factors.

Practice Effects

The main conclusion concerning practice effects is that they are surprisingly small. When naive, the *Ss* were slightly higher in constancy than when more practiced, and most of the drop apparently came in the first few minutes of judgments. Perhaps this drop was the result of an analytical attitude quickly suggested by the laboratory situation.

Practice seemed to have the effect of decreasing inter-individual variability due to familiarity with the manipulative and perceptual task, and perhaps to the growth of a subjective standard of reference.

Summary

1. Shape constancy was studied when a square plate was rotated on a vertical axis until it appeared equal in shape to a rectangle. Four rectangles of varying widths were used.

2. Fifty university students were the *Ss*. Each served in two one-hour

sessions and made a total of 52 settings for each of the four rectangles.

3. The index of constancy (Brunswik Ratio) decreased significantly as angle of rotation (from the frontal-parallel plane) increased.

4. The variability of the settings (measured in terms of the width of the stimulus as an image) was greater for the two large angles of rotation than for the two small ones.

5. The variability of the BR's did not change with angle of rotation.

6. A wide range of individual differences in degree of constancy was found.

7. Individual consistency in relative degree of constancy for the various angles of rotation and from session to session was high.

8. There were small decreases in degree of constancy within sessions, especially in the first part, and from session to session.

9. It was suggested that for any given situation and organism there is a limit on absolute amount of "regression to the real," and that this limit is approached asymptotically. The result is the function stated in point 3, above.

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SOUND LOCALIZATION WITH CONFLICTING VISUAL AND AUDITORY CUES [1]

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The perceived direction of a sound coming from a visible source is determined through the use of both visual and auditory cues. This has been established in experiments that have brought the two types of cues into conflict. In one kind of study (e.g., **1, 2**) the conflict has been created through inversion and reversal of the visual field by use of special lenses; in another kind (e.g., **10**), the paths of sound to the two ears have been reversed by means of a pseudophone. The results obtained have been mainly qualitative in nature, which made it difficult to compare the effects of various experimental conditions. One purpose of the experiments described here was to develop an objective, quantitative procedure for evaluating the roles of visual and auditory experiences in sound localization.

Previous investigations using conflict procedures neglected the important problem of differences among people in manner of integrating conflicting cues. Thus only a single *S* or a few *Ss* were used, so that no record was available of the range of performances that may occur under conditions of conflict. Moreover, no attempt was made in most instances to evaluate the *S*'s perception under carefully standardized test conditions, a necessary procedure if differences among *Ss* are to be detected and measured.

The findings of other studies concerned with the integration of conflicting sensory impressions have pointed out the necessity of considering the problem of individual differences. These studies (**4, 6, 7, 8**) investigated the manner in which people utilize visual and postural experiences in perceiving the position of an object in the field, of the whole field, or of their own bodies in relation to the upright. It was found that people differ greatly in extent of reliance on visual impressions as a basis for determining the upright.

In order to ascertain whether a given degree of dependence on visual experiences, as revealed in these orientation situations, characterizes *S*'s perception under a diversity of circumstances, it was necessary to observe the same *Ss* in other perceptual situations requiring integration of visual and other experiences. The auditory-visual conflict, which juxtaposes visual and auditory rather than

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visual and postural experiences, offered one situation of this kind. Before such a study of self-consistency in perception could be carried out, however, it was necessary to develop a carefully standardized test for evaluating the *S*'s manner of integrating visual and auditory cues, and to determine the extent of differences in perception among *S*s tested under identical conditions. This was attempted in the experiments described here. In a later report the relation between performance in this situation and in a variety of other perceptual situations will be considered.

Apparatus

The general method consisted of having *S* locate the source of a sound under conditions of conflict between visual and auditory cues. The visual indication of the sound source (*E*'s mouth) remained fixed in the median plane, while the auditory indication (difference in time of arrival of sound at the two ears) was systematically shifted. The apparatus employed for this purpose, based on the von Hornbostel-Wertheimer technique (3), transmitted the sound through two telescoping brass tubes that could be varied in length (see Fig. 1). The tubes (inside diameter ¾ in.) were 53 in. long when fully extended, and allowed a 21-in. variation of sound path. The outer sections were fixed, and the ends of the movable sections were supported by small rollers that traveled on the surface of the table. Tube-extension length was measured by centimeter scales.

Pinion gears, attached to 2-rpm synchronous gear-reduction motors, drove racks connected to the movable sections of tubing at the rate of 1 cm. in 8 sec. Transmission of motor hum was minimized by rubber couplings and mountings. A pin clutch between motor and pinion gear permitted quick disengagement of the motor and manual setting of tubes and racks. The driving motors were controlled by pedal switches. When one pedal was depressed, the motors started to rotate in opposite directions, lengthening one tube and shortening the other. Depression of the other pedal caused both motors to reverse direction and the tubes to shorten or lengthen in the opposite direction.

Preliminary experiments indicated the desirability of having a sound-producing object in which the onset and duration of sound were

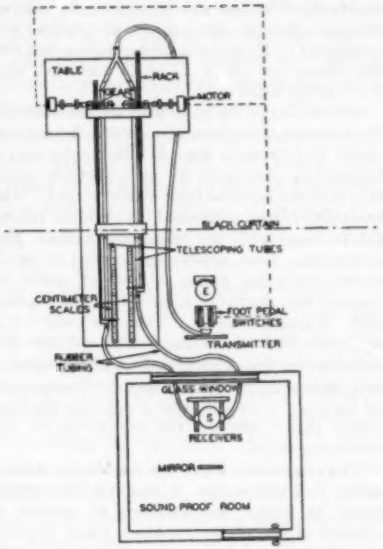

Fig. 1. Apparatus used for presenting sound with conflicting visual and auditory cues

correlated with distinct visual changes. It was found that the human face during speech was the most suitable "object." Accordingly, *E* himself, speaking to *S*, was the source of sound. The *S* saw only *E*'s face, and his mouth in particular. In order that he might seem more a "person" than a mechanical "sound source," *E* read stories to *S*. To prevent direct transmission of the sound, *S* was enclosed in a soundproof chamber. He sat on a chair equipped with a headrest, with his back to a double-paned window.

As frequently happens when sound is delivered directly into the ears, the tube system described above caused many *S*s to experience a front-back reversal of the sound. This, added to the experimental displacement of the sound to left and right of its source, often divorced the auditory cues from their visual source to such an extent as to make them appear entirely unrelated. This difficulty was eliminated by the simple expedient of placing the sound source (*E*) directly *behind S*, who then saw him reflected in a small mirror (see Fig. 1). Under these conditions the apparent direction of sound and the apparent position of its source coincided, creating an entirely natural impression. The mirror was approximately 18 in. from *S*'s eyes, and its height was adjusted so

that only *E*'s face was reflected. The sound coming through the adjustable tubes was conducted to *S*'s ears via rubber tubing and two flat plastic ear pieces, 2¼ in. in diameter, with ¾-in. center holes.

The *E*, seated on an adjustable stool outside the soundproof window, was directly behind and about 4 ft. distant from *S*. He spoke into a transmitter, concealed by an adjustable stand that held the material from which he read. The transmitter was connected by rubber tubing (12 ft. long) with the telescoping tubes. The connections were removable so that a small phone, connected to an audiometer, could be inserted into the tubes to carry out the hearing tests described below. The *E*'s seat was equipped with a headrest, to stabilize his reflection in the mirror; and a black curtain, hung behind it, provided a uniform background for his face. From this seat *E* operated the foot pedals that controlled the movement of the telescoping tubes.

The amount by which the sound was shifted before *S* detected that it had left the visible source at center was assumed to provide a measure of the extent to which visual impressions contributed in his determination of the direction of the sound. The magnitude of the shift was measured by the difference between the lengths of the two tubes.

Procedure

Audiometer tests.—The first part of the procedure consisted of two simplified audiometer tests, which checked *S*'s hearing threshold for each ear separately, with and without earphones. The audiometer was Western Electric type 6 BP, calibrated in terms of db hearing loss. The first test was at a frequency of 1024 cps, while *S* was seated outside the soundproof room. Thresholds were obtained for each ear, so that the difference could be used as a standard against which to judge the fit of the apparatus.

After this test *S* was brought into the soundproof room and was retested at the same frequency, this time with the audiometer tones transmitted through the tubes of the sound-shifting apparatus. The earphones were readjusted until *S*'s threshold was under 10 db. They were also readjusted if the difference between the ears was more than 3 db greater than the difference in the first audiometer test. Thus, gross differences in hearing acuity between the ears, caused by improper fitting of the earphones, were largely eliminated. All *S*s used in the experiment had thresholds within the range −7 to +10 db.

Preliminary instructions.—After the audiometer test, *S* was told that some stories would be read to him from directly behind his chair outside the booth, and that his task was to notice where the sound of *E*'s voice came from. He was instructed to watch *E*'s mouth carefully, and by prearranged hand signals to signify whether the voice was coming from *E* at center, from the left, or from the right.

"Subjective center."—The *E* started by reading a story selected for a practice trial. The telescoping tubes of the apparatus were made equal in length, so that the sound would be centered objectively. If, as happened occasionally, *S* did not accept "objective center" as the true center, *E* moved the tubes until *S* signalled "center." This was considered "subjective center" for the particular *S* for that trial, and was used as his standard in computing the amount of displacement of the sound.

Displacement test.—The *S* was then told that the sound of *E*'s voice might move from center and to signal when this happened. He was also told that if he heard another low sound he was to disregard it.[2]

The *E* proceeded to move the telescoping tubes until *S* reported that the sound was coming from one side. He checked this response by continuing to read for 10 sec. more (with the tubes in the same position) and again asking *S* where the sound came from. If he did not alter his first response, the trial ended. If *S* changed his response during the checking period, the sound was moved farther to the same side until he signalled that it came from the side, or until the maximum difference of 50 cm. between the two telescoping tubes was attained.[3]

After the practice trial, and at the end of each subsequent trial, *S* was questioned about the content of the stories read. If he failed to answer the questions correctly, he was told that attention had to be paid to the stories as well as to the location of the sound. After completion of the testing session, *S* was also asked a series of questions relating to his performance.

Test conditions.—The procedure described above for the practice trial was followed in the 16 subsequent test trials. These were given under two conditions. (a) *"Eyes open":*

[2] The humming noise from the motors that moved the telescoping tubes.

[3] If *S* continued to vary his response after resumption of the trial, i.e., if he again reported "center" during the checking period after previously reporting "side," *E* tried to determine whether the basis for the shift was the absence of the humming sound of the motors during the checking period. If this seemed to be the case, *S* was reminded of the instruction to listen only to the sound of *E*'s voice and to judge its location on that basis alone.

S watched *E*'s face throughout the trial; and, by checking in the mirror, *E* made certain that *S* followed this instruction. Scores on these trials measured sound localization in the presence of conflicting visual and auditory cues. (b) "*Eyes closed*": The same procedure was followed, but *S* was not permitted to see *E*; that is, scores on these trials measured sound localization with auditory cues alone available. The measurement used for evaluating performance under both test conditions was the difference in length of the two tubes when *S* first perceived the sound as "off-center," except for cases where a new subjective center had to be established. Four eyes-open trials were followed by eight with eyes closed and then four more with eyes open. There was an equal distribution of trials in which the sound moved to the left and to the right, in the order ABBA, repeated, followed by BAAB, repeated.

On all trials *E* read stories from Aesop's Fables. The same stories were always used on a given trial, and presented in the same order to all *Ss*. Although most *Ss* could be tested in a single session of approximately an hour's duration, six male and ten female *Ss* required two sessions. In these cases, an attempt was made to terminate the first session after the eighth trial; and another audiometer test was given at the beginning of the second session to insure that the earphones fitted properly.

Subjects.—The *Ss* were 97 Brooklyn College students, 49 men and 48 women, recruited from undergraduate psychology courses. Two different *Es* administered the tests: one *E* tested 24 men and 18 women; the other 25 men and 30 women.

Results

Adequacy of procedures.—It was necessary to determine whether the sound, in its initial central position, seemed to *S* to emanate from *E* or to be located in his own ears or near his head. Most *Ss* (83%) accepted the situation as being quite natural, in that they experienced the sound as coming from the region of *E*.

In general, when the two tubes were of equal length, *Ss* perceived the sound as issuing from the central position. On 90% of all trials for women *Ss*, and on 87% of all trials for men *Ss*, the sound was perceived at center at the beginning of the trial; in the remaining cases a new subjective center had to be determined.

No difference in results was found according to whether the sound was shifted to left or to right. For both men and women, in both the eyes-open and the eyes-closed condition, the means were almost identical for trials on which the sound was shifted to the left and trials on which it was shifted to the right; and in no single instance was a significant difference found.

Only a few *Ss* reported that the humming noise of the motors distracted them from the sound of *E*'s voice. Moreover, the mean scores for these *Ss* were almost identical with those for the entire group. Only three female *Ss* and two male *Ss* stated that when the motor noise stopped the sound of *E*'s voice seemed to return to center, and in none of the five *Ss* did this happen consistently.

Possible differences in attention to the stories did not seem to be a factor in our results. Only 10% of the women and 9% of the men reported, upon questioning, that they had attended more to the content of the stories than to the location of the sound; and their mean scores were not higher than those of the rest of the group. Also, those *Ss* who gave the largest number of correct answers to questions about the stories did not obtain higher scores.

No evidence was found of experimenter differences. The scores of the *Ss* tested by the two *Es* were compared, for men and women separately. No significant differences were found for either the eyes-closed or the eyes-open condition.

There was the possibility that in order to be more certain of their decisions some *Ss* waited a while, after hearing the sound come from the side, before reporting this fact to *E*. This could serve as a nonperceptual

factor that would increase *S*'s score. It was found that in the eyes-open condition *Ss* who reported a tendency to delay before announcing their decisions had higher scores than the group as a whole. Their average score for the eyes-closed condition, however, was the same as that of the entire group. This indicates that the tendency to delay is not generalized, but is specific to the eyes-open condition for these *Ss* and reflects the greater difficulty they encountered with this perceptual task.

Effect of the visual field.—A comparison of mean scores for eyes-closed and eyes-open trials (Table 1) reveals that *seeing* the sound originate at a given position influenced *Ss* greatly in determining the location of the sound. Male *Ss* permitted the sound to be displaced 64% farther to the side with eyes open than with eyes closed; female *Ss* permitted it to be displaced 109% farther. In both cases the increase is significant at the 1% level of confidence. When these results are translated into terms of equivalent direction angles, the average angle of deviation of the sound from center in the eyes-closed trials is 17° for men and 18° for women.[4] In eyes-open trials, the average angle is 28° for men and 38° for women. Since the smallest noticeable difference in direction near the median plane is approximately 3° (9), the difference between the eyes-closed and eyes-open conditions is very striking. There is thus confirmation of the fact that perception of the direction of a sound depends not only on auditory cues (such as difference in time of arrival of the sound at each ear) but also on visual impressions received from the object producing the sound.

TABLE 1

MEANS AND *SD*'S FOR EYES-OPEN AND EYES-CLOSED CONDITIONS

	Men (N = 49)		Women (N = 48)	
	Eyes-open	Eyes-closed	Eyes-open	Eyes-closed
Mean*	8.5	5.2	11.3	5.5
SD	6.4	2.7	9.3	3.1

* Mean difference between lengths of tubes to the two ears (in cm.) when deviation of the sound from center was noted.

Further evidence of the importance of visual impressions in the perceived location of a sound is found in certain difficulties encountered by *Ss* in making their judgments. One of these difficulties was the "shift back to center" already described. This was more frequent in the eyes-open than in the eyes-closed trials. Among men there was an average of 3.8 shifts per *S* in the eyes-open trials and only 1.7 in the eyes-closed trials; among women, the average number of shifts per *S* was 5.8 and 1.8, respectively. The difference between the eyes-open and eyes-closed conditions was significant at the 1% level for both men and women. In part, these shifts reflected *Ss*' efforts to make their judgments exactly correct, and to this extent they occurred under both conditions. In the eyes-open condition, however, when auditory cues became stable during the checking period, thereby receiving less attention than when they were undergoing change, visual impressions tended to "take over" once more, with the result that the sound was "pulled back" to its visually indicated source.

[4] These unusually large thresholds are undoubtedly attributable to the particular procedure used. Here the sound was started in the median plane and moved *continuously* until *S* signalled "side." Other experiments in which lower thresholds have been obtained involved the presentation of sound stimuli in a series of *discrete* positions.

In some instances the shift-back-to-center phenomenon took an extremely dramatic form. In supplementary tests, conducted with several *Ss* who showed extreme dependence on visual impressions, the sound was delivered under the eyes-closed condition with a 50-cm. differential between the two tubes. In these circumstances the sound was perceived as off-center. Then, with the tubes remaining in the same position, *S* was asked to open his eyes, so that he could see *E* speaking to him from the center position. Some *Ss* had the immediate impression that the sound had returned to center. When asked to close their eyes and make another judgment, they once more perceived the sound as off-center. By the simple procedure of having these *Ss* close and open their eyes, it was possible to cause their perception of the sound to shift away from center and back to center.

As noted in the "Procedure," it occasionally happened that *S* experienced the sound as off-center although the tubes were equal in length, and a new "subjective" center had to be established. This probably occurred when there was a very slight discrepancy in the fit of the two earphones and *S* was extremely finicky about his judgments. If visual factors play a role in sound location, it is to be expected that with his eyes open *S* would be more likely, despite such discrepancies, to accept the objective center (equal length of the two tubes) as true center than when his eyes were closed. The direction of results is in accordance with this expectation for both sexes. For women, there was an average of 1.0 new "subjective" centers per *S* in the eyes-closed trials, and .6 in the eyes-open trials; among men, the average number of new centers was 1.1 and 1.0, respectively. (The difference for women is significant at the 5% level, whereas that for men is not significant.)

Sixty-two per cent of the men and 77% of the women reported that they found the eyes-open trials more difficult than the eyes-closed trials. The generally higher scores in the eyes-open trials are thus associated with a conscious awareness of the effect of the visual cues, and with greater difficulty in forming judgments.

To investigate variability in performance, the range between each *S*'s lowest and highest scores was determined for both eyes-open and eyes-closed trials. In the eyes-closed trials the mean range was 6.6 cm. for men and 8.3 cm. for women. In the eyes-open trials the mean ranges were 12.7 cm. and 20.2 cm., respectively. (For men the difference in mean range between the eyes-open and eyes-closed scores is significant at the 5% level; for women it is significant at the 1% level.) Thus, in both men and women, variability of performance was greater with eyes open than with eyes closed. This is not surprising, since with his eyes open *S* had two standards available in making his judgments. He could establish some compromise between these standards, or he could shift his primary reliance from one to the other, so that the results would be less consistent than when only a single standard was available.

Sex differences.—It is noticeable in many of the data cited that women seemed to be more strongly influenced by visual impressions than men. Although the difference between the sexes in the various measures used generally proved to be not significant, they are in the same direction throughout, and in the direction to be

expected on the basis of previous investigations (5).

Briefly, the following indications of such a tendency were noted in this experiment: (a) In the eyes-open trials the mean score for women was 11.3 cm. and the mean score for men only 8.5 cm. (Table 1). In the eyes-closed trials, with no visual standard present, the scores for men and women were about the same (5.2 cm. and 5.5 cm., respectively). (b) The number of "shifts back to center" in the eyes-open trials averaged 5.8 for women and only 3.8 for men; but, again, in the eyes-closed trials the results for the two sexes were about the same (1.8 shifts for women and 1.7 for men). (c) The average number of new subjective centers that had to be established in the eyes-open trials was .6 for women and 1.0 for men. In the eyes-closed trials the scores were again almost identical (1.0 for women and 1.1 for men). (d) Finally, whereas 37 women (77%) reported the task of locating the sound more difficult with eyes open than with eyes closed, only 28 men (62%) found the eyes-open condition more difficult. Also, 8 women (18%) but only 2 men (4%) reported that they visualized *E* at center during the eyes-closed trials. For none of the data cited thus far were the differences between the sexes significant.

In addition to showing a consistent tendency toward greater reliance on visual impressions, women proved more variable than men under conditions of conflicting auditory and visual standards. In the eyes-open trials the mean range for men was 12.7 cm., the mean range for women 20.2 cm. (The difference is significant at the 1% level.) In the eyes-closed trials, on the other hand, the mean ranges were similar (6.6 cm. for men and 8.3 cm. for women), and the difference between them was not significant.

Individual differences in performance.—The standard deviations in Table 1 indicate that *S*s tended to be fairly similar in their perception when auditory cues alone were available, but showed marked individual differences under conditions of conflict between auditory and visual cues.

Odd-even reliabilities were quite high for both the eyes-closed and the eyes-open scores, particularly in view of the complexity of the task involved. For eyes-closed trials the values were .86 for men and .76 for women; for eyes-open trials they were .75 and .80 for men and women, respectively. These latter high values indicate that *S*s, differing in their manner of integrating conflicting visual and auditory experiences, tended to be highly self-consistent in this regard throughout the series of eight trials.

Further evidence of stability of performance was obtained by comparing the mean scores for the first four and last four trials under each condition. For the eyes-closed trials, the means for the first and second halves were 5.3 cm. and 5.1 cm. for men, and 5.8 cm. and 5.1 cm. for women. For the eyes-open trials, the means for the two halves were 9.5 cm. and 8.0 cm. for men, and 11.7 cm. and 10.5 cm. for women. A slight improvement is indicated, but in no instance is the difference significant. The absence of any significant improvement with experience is in keeping with the interpretation that the *S*'s mode of perception here must have a deep-seated basis.

Correlations were computed between scores in eyes-closed and in eyes-open trials, and were found to be fairly high: .70 for men and .69 for women. In view of the significantly

higher scores in the eyes-open trials, it may be concluded from these correlations that *Ss* tended to show proportionately similar amounts of increase between their eyes-closed scores and their eyes-open scores. At the same time, the correlations are sufficiently low to indicate that some *Ss* were relatively more affected by the visual standard than were others.

Discussion

It has been found that visual factors, along with auditory factors, may play a decisive role in perceiving the direction of origin of sound. There are marked differences among people, however, in the extent to which each type of cue is utilized when both are available as bases for sound location; and a given way of perceiving tends to characterize a person consistently throughout a series of trials. Previous studies (**4**, **6**, **7**, **8**), which investigated a different area of perception (perception of the upright) but also imposed conditions of conflicting sensory experiences (visual and postural), have arrived at the same basic finding. That is, they have shown that people differed in manner of integrating the available cues, and that emphasis on visual experiences or on postural experiences remained a stable feature of a person's perception under different test conditions. There are thus several lines of evidence to show that, within limits, the perceptual experiences of people may differ despite identical conditions of stimulation, and to demonstrate the important role of personal factors, unique to the individual, in determining the nature of his perception.

With eyes open, so that auditory and visual cues were available as bases for perceiving the location of a sound, differences in results were observed between men and women, with women showing a tendency to locate the sound closer to where they *saw* it originate than did men. Although in the present situation the differences between the sexes were generally not significant, they were always in the same direction. Moreover, they were consistent with results obtained in a variety of other situations (**5**), very different from the ones used here, in which the sex differences generally did prove to be significant. So, in studies of perception of the upright, women to a significantly greater extent than men "went along with" the upright of the prevailing visual field, in preference to accepting the gravitational upright determined through postural experiences. There is thus a consistent indication that women more than men depend on impressions received from the visual field, and do so at the expense of other sensory experiences, such as the auditory or postural. Both here and in the other studies cited, moreover, no sex differences at all occurred when only one standard (auditory or postural) was available for perception.

In this experiment an auditory threshold was established for each *S*, using standard psychological procedures. It is impressive that for almost every *S* this auditory threshold changed when the visual conditions of the test (that is, non-auditory factors) were altered. Furthermore, the relative amount of change in threshold was to some extent different for different *Ss*. Clearly, the presence of visual cues along with auditory cues involves not only the fact of an additional sensory stimulus, but also the complex problem of the unique way in which each person integrates the experiences from different sense modalities. Thus it is plain that even so apparently specialized a sensory function as perception of the location

of a sound cannot be understood in all its implications when studied in isolation. Its full understanding requires reference to related events in other sense organs and to the nature of the organism in which it occurs.

Summary

The purpose of this study was to develop a quantitative procedure for evaluating the roles of visual and auditory cues in sound localization, and to investigate individual differences in manner of integrating these cues. The *S* was required to locate the direction of a sound under conditions of conflicting visual and auditory cues. The visual indication of the source of sound (*E*'s mouth) remained fixed, at a central position, while the auditory indication was shifted to left and right by changing the relative lengths of the two tubes which carried the sound to *S*'s ears. The sound was shifted slowly from the center to one side, and *S* had to indicate the first point at which he perceived it as coming from off-center. The amount by which the tubes were changed before *S* detected that the sound had left its visible source provided a measure of the extent to which visual impressions served him as a cue in sound localization. Ninety-seven *Ss* were tested in this condition, which provided conflicting visual and auditory cues, and in addition received control trials with eyes closed.

Mean scores for the eyes-open trials were significantly higher than those for the eyes-closed trials, indicating that *Ss*' perception of the direction of the sound was markedly affected by whether or not they saw its source of origin. In the eyes-open trials particularly there were marked individual differences in performance, and there was evidence that *Ss* remained stable in their perception. Women tended to rely more on visual impressions than men, though the differences between the sexes were generally not significant. The individual differences and sex differences found were related to those observed in other areas of perception when the *S* was required to integrate conflicting sensory experiences. The evidence suggests that the understanding of even so seemingly specialized a function as location of the source of a sound requires knowledge not only of related activities in other sense organs but of the nature of the organism as well.

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EXPERIMENTS ON SENSORY-TONIC FIELD THEORY OF PERCEPTION: IV. EFFECT OF INITIAL POSITION OF A ROD ON APPARENT VERTICALITY[1]

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The present investigation has its origin in certain observations made in previous studies on the perception of the vertical (6, 7, 8, 9). In these experiments *S*'s task was to adjust a luminescent rod so that it appeared vertical under various test conditions. For methodological reasons the rod was always presented in an initial position of tilt either to the left or the right: it was noticed that these starting positions affected the final adjustments to apparent verticality.[2]

This influence of starting position on the final position in which a rod is perceived as vertical seems to be of particular significance for the sensory-tonic field theory of perception (8). An essential tenet of that theory is the notion of continuous interaction of object and organism. Such a conception means not only momentary interaction of these two elements. It implies their interplay in time: the initial position of the object may affect the status of the organism which in turn may influence the subsequent perception of the position of the object.

The present investigation attempts to study these effects systematically.

METHOD

Stimulus object.—In all situations the tests were carried out in a dark room. The task was to adjust a luminescent rod which could be rotated in the frontoparallel plane so that it appeared vertical. The luminescent rod, 39 in. long and 1 in. wide, was pivoted at its center, and its angular displacement was read off in fractions of a degree from a protractor.

Experimental design.—The major variable studied was the starting position of the luminescent rod, i.e., the initial position in which the rod was placed at the beginning of a trial. Three starting positions were employed: (A) Perpendicular: 0°; (B) 30° CCW; and (C) 30° CW. Each *S* was tested under each starting position. For each *S* one of the six possible sequences (ABC, ACB, BAC, etc.) was used. The design permitted evaluation of the effect of starting position, sequence, ordinal position,[3] sex, and individual differences. Four *S*s, two male and two female, were tested in each sequence, making a total of 24 *S*s (see Table 1). An over-all analysis of the data, as well as a separate analysis for each sex, was carried out.[4]

Procedure.—Ten trials were given for each of the three starting positions, making a total of 30 trials. Following each set of 10 trials for a particular starting position there was a 2-min. rest. The *S* had his eyes covered with goggles between test trials.

For the 0° starting position, each trial was executed in the following manner: The rod was shifted from the initial position in half degree steps. At each position *S* reported whether the rod was tilted left, whether it was vertical or tilted right. At first the rod was moved CCW (CW) until *S* reported it was left (right); then it was moved in the opposite direction, through the positions reported as vertical, until it was tilted right (left). Thus the range of positions in which *S* perceived the rod as vertical was established for each trial.

For the trials with the rod starting in the 30° position the magnitude of steps decreased as the vertical was approached: the rod was moved in

[1] This investigation was supported by a research grant from the National Institute of Mental Health, of the National Institutes of Health, Public Health Service.

[2] See also Witkin and Asch (11).

[3] By the effect of ordinal position or ordinality is meant the influence that temporal position within a test series has on response, i.e., whether there is significant variation in response irrespective of sequence or specific test conditions; for instance, practice or fatigue effects. See (5).

[4] We wish to express our appreciation to Dr. L. S. Kogan for aid in analyzing the data.

TABLE 1

DESIGN OF EXPERIMENT

Number of Subjects	Sequence	Ordinality		
		I	II	III
2 Males 2 Females	1	A*	B*	C*
2 Males 2 Females	2	A	C	B
2 Males 2 Females	3	B	A	C
2 Males 2 Females	4	B	C	A
2 Males 2 Females	5	C	A	B
2 Males 2 Females	6	C	B	A

*A, B, C refer to the major experimental variable (starting position of 0°, 30° CCW, and 30° CW respectively).

5° steps up to the position of 10°; then it was moved in 1° steps until 5°; and finally, .5° steps were used until *S* reported that the rod was tilted to the opposite side. Thus, again the range of positions in which the rod appeared vertical was established for each trial with a tilted starting position. Each judgment within a trial had to be made as quickly as possible: approximately 1 sec. was allowed.

Measures employed.—The position in which the rod looked vertical to *S* (apparent vertical) was measured in degrees of tilt with reference to objective vertical (plumb line). Thus, all measures of the position of the luminescent rod are defined in terms of the perpendicular. Arbitrarily we designate an angular position clockwise (CW) of objective vertical as "+" (tilted right) and an angular position counterclockwise (CCW) as "−" (tilted left). The midpoint of the range of positions of apparent verticality was obtained for each test trial. The algebraic mean of the ten midpoints for each test condition was used as a measure of the perception of verticality.

RESULTS

Table 2 presents a summary of the analysis of variance taking into account five variables: starting position, sequence, ordinality, sex, and individuals. The *F*-tests for starting position and individuals within sequence are significant. When the starting position is 30° CCW, the apparent vertical has a mean tilt to the left of 1.7°; when the starting position is 30° CW, the apparent vertical has a mean tilt to the left of .1°. When the rod is started from a perpendicular position (0°), the apparent vertical falls in between the means for the other conditions, i.e., it is tilted .4° to the left. It can be seen from the *t*-tests that under right starting position the mean differs significantly from that of the left starting position. The effect of left starting position, though not that of right starting position, differs significantly from perpendicular starting position.

Tables 3 and 4 summarize the analyses, separate for women and

TABLE 2

SIGNIFICANCE OF DIFFERENCE AMONG TEST CONDITIONS: WOMEN AND MEN COMBINED

F-tests

Source of Variance	*df*	Mean Square	*F*
Between all individuals	23	3.87	—
Sequence	5	0.95	<1.00
Sex	1	0.18	<1.00
Individuals within sequence	17	4.95	3.96*
Starting position	2	17.37	13.90*
Ordinality	2	1.14	.91
Error	44	1.25	
Total	71		

Means

Starting Position	30° CCW	0°	30° CW
Mean (degrees)	−1.7**	−0.4	−0.1

t-tests

Mean differences

	30° CCW	0°	30° CW
30° CCW (Left)	—	1.3*	1.6*
0°		—	0.3
30° CW (Right)			—

*Significant below .01 level of confidence.
**A minus value indicates that apparent vertical is CCW of the perpendicular.

TABLE 3

SIGNIFICANCE OF DIFFERENCE AMONG TEST CONDITIONS: WOMEN

F-tests

Source of Variance	*df*	Mean Square	*F*
Between all individuals	11	3.20	—
Sequence	5	1.98	1.28
Individuals within sequence	6	4.22	2.72*
Starting position	2	18.20	11.74**
Ordinality	2	1.25	0.81
Error	20	1.55	
Total	35		

Means

Starting Position	30° CCW	0°	30° CW
Mean (degrees)	−2.2***	−0.4	+0.1

t-tests

Mean differences

	30° CCW	0°	30° CW
30° CCW (Left)	—	1.8**	2.3**
0°		—	0.5
30° CW (Right)			—

* Significant below .05 level of confidence.
** Significant below .01 level of confidence.
*** A minus value indicates that apparent vertical is CCW of perpendicular. A positive value indicates that apparent vertical is CW of perpendicular.

TABLE 4

SIGNIFICANCE OF DIFFERENCE AMONG TEST CONDITIONS: MEN

F-tests

Source of Variance	*df*	Mean Square	*F*
Between all individuals	11	4.87	—
Sequence	5	5.04	6.15*
Individuals within sequence	6	4.74	5.78*
Starting position	2	2.68	3.27
Ordinality	2	0.17	0.21
Error	20	0.82	
Total	35		

Means

Starting Position	30° CCW	0°	30° CW
Mean (degrees)	−1.2**	−0.5	−0.4

* Significant below .01 level of confidence.
** A minus value indicates that apparent vertical is CCW of the perpendicular.

men. The results for women conform with the over-all picture presented above. As to the men, it may be noted that sequence and individuals within sequence are significant. The shifts of apparent vertical due to starting position, though only approaching significance, are in the same direction as obtained for women.

DISCUSSION

This study demonstrates that the position of the apparent vertical, in general, depends on the position at which the rod is placed at the beginning of a trial: viz., the apparent vertical is always closest to the position in which the rod was set initially for that trial.

Shifts of the apparent vertical have been observed in previous papers of this series. We have shown there that "extraneous stimulation"[5] (6, 7) and body tilt (9) serve as factors influencing the position of apparent vertical. These findings have been interpreted in a general way as being in accord with the tenets of the sensory-tonic field theory of perception. The present study differs from the earlier ones in an important respect: in the previous studies the organismic state was experimentally manipulated, whereas here the stimulus object and its manner of presentation was manipulated. Therefore, the information coming from this study on starting position obligates us to expand and to specify our hypothesis in such a way that it will account for all of these effects.

For this purpose, the notion of verticality must first be clarified. Practically all earlier investigators

[5] By this term we mean any stimulation to the organism which comes from a source other than the object perceived. For instance, while judging the position of a line, *S* is exposed to an auditory stimulus.

who dealt with the problem of the vertical and the experimental conditions which make for shifts in apparent vertical have dichotomized object and person, and conceived of a vertical line as existing in a relatively isolated space. In keeping with this dichotomy some of the attempts which have been made to analyze the singular character of the vertical (horizontal) have been in terms of external or physical criteria, such as gravitation; these attempts did not advance toward organismic interpretations. Explanations of this sort do not seem capable of treating adequately the basic question of interaction. If one accepts the notion of a sensory-tonic field in which object and organism are interacting elements, some of the puzzling problems such as the meaning of "preferred positions," the paradox of interaction, etc., can be solved or disappear.

One of the inferences from the sensory-tonic field theory is that verticality is a preferred direction because this direction is in tune with some inherent characteristics of the organismic state. At this point it seems advantageous to introduce the concept of equilibrium, generally used in biological dynamics. (It is an important construct of the sensory-tonic field theory that there is a body equilibrium which establishes itself or re-establishes itself with reference to intra- and extra-organismic stimulation.)When the body is erect, n apparently vertical line is a line commensurate with a coordinate of the existing body equilibrium. Stated in dynamic terms a line, seen vertical, can be defined as one which does not interfere with, or does not disturb the body equilibrial state. Conversely, lines perceived as tilted are lines which can be thought to be out of tune with the existing body equilibrium. An organism confronted with a tilted line may tend to change its equilibrial state to one more or less commensurate with the line; the outcome of such a tendency will then be that the line, though objectively tilted, will appear vertical. This deduction is in keeping with the definition of apparent verticality given above.

(In order to develop these constructs further and provide an interpretation of starting position effects, we may refer to results concerning the effects of body tilt (9), and of asymmetrical stimulation to the erect body) (6, 7) on perception of the vertical. (In general, it has been established that the position of apparent vertical is angularly displaced opposite to the side in which the body is tilted, and also opposite the side to which the stimulation is applied) We assume that under these various circumstances the position of apparent vertical has shifted owing to a shift of the equilibrial state induced by body tilt or extraneous stimulation. Some support for the interpretation in terms of equilibrial shifts comes from neuropathological evidence. As is known from cerebellar cases, tilting of the body results in falling to the side of tilt unless counteracted (4). The same holds for extraneous stimulation by light, etc. (Thus, stabilization under conditions of body tilt and extraneous stimulation ensues from a counteractive force (increased tonus) opposite to the side of tilt or stimulation.) In brief, body tilt, or extraneous stimulation, increases the neuromuscular tonus to one side (primary force) and counteractive forces are brought forth in order to re-establish a new stable dynamic equilibrium. Such a new equilibrial state under tilt, or stimulation to the left, and tilt, or stimulation to the right, is represented in Fig. 1. The inference is, as

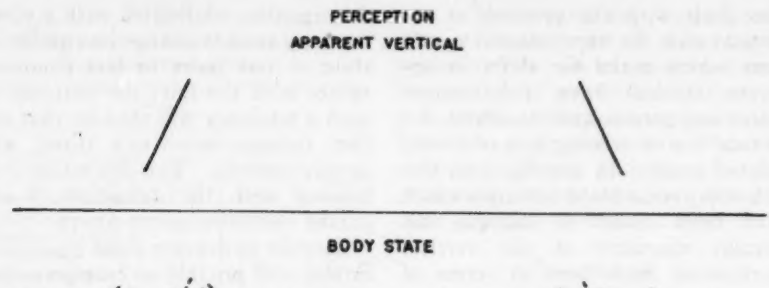

FIG. 1. Hypothetical representation of body equilibrial state.

pictured in the figure, that the new equilibrial axis under extraneous stimulation is angularly rotated to the side of the counteractive force; this means that the apparent vertical has to be displaced correspondingly to be in tune with the newly established equilibrial axis of the body.

This hypothesis exemplifies what the sensory-tonic field theory generally implies, namely, that the observed shifts of the apparent vertical do not occur in a self-contained visual field but occur in a sensory-tonic field comprising object and body.

The constructs described above may then be applied to the interpretation of starting position effects in the following way. As assumed above, a visual line leaves the body equilibrium undisturbed if it coincides with the existing equilibrial axis. Correspondingly, a tilted line can be assumed to be incommensurate with the equilibrial state of the erect body. If one agrees that the organism tends to maintain an equilibrium, one might, therefore, expect tendencies toward re-establishment of equilibrium when the erect organism is confronted with tilted lines. Evidence in support of such an organismic tendency can be found in the work of Gibson and Radner (3) on so-called adaptation to the vertical in perceived tilted lines. Gibson has shown that a line tilted less than 45° appears progressively less tilted during the course of inspection. Other studies such as those concerning observations on tilted fields (1, 2, 10) also provide evidence for an adaptation tendency.

Some attempts have been made to interpret so-called adaptation effects by lawful trends within the framework of configurational theory. In particular the construct of "normalization" has been used to account for effects such as those shown by Gibson. The notion of normalization is a useful term at the descriptive level of interpretation. In order to understand the psychodynamics of processes underlying that effect, we feel that one has to advance beyond phenomenological analysis.

The sensory-tonic field theory of perception aims to understand the general dynamics of object-body relationships rather than to provide an interpretation specific to adaptation per se. The feasibility of such broader interpretation might become clear from the following discussion which tries to tie together the shifts of verticality due to starting position and those depending on extraneous stimulation and body tilt.

For that purpose, we may return to Fig. 1 which depicts the positions of lines assumed to be undisturbing to equilibrial states under conditions of extraneous stimulation to the left and to the right. We may now ask the question in reverse. What are the equilibrial states which are commensurate with tilted lines? This question can be answered by this consideration: Given an equilibrial state induced by extraneous stimulation such as that depicted in Fig. 1A, a line tilted objectively to the right appears perpendicular. If, conversely, a line is objectively tilted to the right, and then through inspection becomes perceived as perpendicular, the equilibrial state can be then assumed to be that pictured in Fig. 1A.

Similarly under tendencies of stabilization of equilibrium, if a line tilted to the left is presented to a subject standing erect, the equilibrial state has to shift to the vector arrangement depicted in Fig. 1B.

As one will note, the inference which has been drawn here is based on the assumption of an invariable relation between the position of a line perceived as perpendicular and a particular equilibrial state: since we know that under induced equilibrial state *Y*, a line is seen as perpendicular when in position *X*, then if a line in position *X* is seen as perpendicular, the equilibrial state *Y* is inferred.

In brief, adaptation to the vertical is here interpreted as an equilibration trend. Under perfect adaptation a tilted line no longer disturbs the equilibrium if the new equilibrial state is in tune with the tilted line. The perceptual effect is that the line now appears vertical.

The effect of starting position can be considered as a partial adaptation effect. That is, an initial line tilt will force the organism toward shifting the existing equilibrial axis in a direction which is in tune with the direction of the line tilt. This has the consequence that the observer will accept a line as the apparent vertical when the line is more or less tilted toward the side of initial line tilt.

Summary

The influence of the position of a rod at the beginning of a trial (starting position) on the final position in which it is perceived as vertical has been systematically investigated. The main finding is that the apparent vertical is always closest to the position in which the rod was set initially for that trial.

These results are viewed here as figural adaptation effects.

Taking the results of this study together with those gained from previous investigations on the effect of postural tilts and extraneous stimulation on the perception of verticality, such adaptation is interpreted within the framework of a general theory which emphasizes body-object relationships. The dynamics underlying these adaptation effects are assumed to be equilibration tendencies within a field that encompasses body and object.

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THE RETENTION OF MATERIAL PRESENTED DURING SLEEP[1]

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There is occasion for great surprise on discovering the exceedingly small number of experiments involving the possibility of learning during sleep. This possibility follows as a corollary to the induction of particular dream states by external stimuli during sleep. Schmidhofer (11) and others (2, 9, 10) are among those who have demonstrated this phenomenon, although the effects shown by Schmidhofer, relating to reduction of terror dreams by suggestion during sleep, are difficult to evaluate since waking suggestion was also carried on. The possibility also follows as a direction of study from the work of Jenkins and Dallenbach (5), Van Ormer (13), and others. Attention should also be drawn to the hypnopedia described in Huxley's *Brave New World* (4).

LeShan's attempt to cure nail-biting in children did utilize sleep suggestion alone (8). A record with 50 repetitions of the sentence, "My fingernails taste terribly bitter," was played six times a night on 54 successive nights to a group of 20 experimental children. None of the children was informed of the experiment. Of the 20 controls, 100% still bit their nails after this period. Of the experimentals, 40% no longer continued the practice. The personalities of the children were not investigated thoroughly.

Elliott (1) reports an unpublished study by Thurstone, who attempted to teach Morse code by presenting stimuli during sleep to a group of 16 naval students. He is supposed to have gotten very promising results.

A more recent and well-controlled study was conducted by Elliott (1). His two groups of 20 each were prepared for the conditions of the experiment by sleeping in the laboratory one night, and being exposed to the apparatus and procedure. The next night, both groups, equated on the basis of learning 15 three-letter, one-syllable words by the anticipation method, again slept in the laboratory. Few of the 55 were able to sleep well the first night, making it probable that they would need rest and sleep the second. An EEG was taken to determine the condition of sleep. The second night the experimental group was exposed to a different list of 15 words repeated a number of times during sleep. The next morning both groups learned the list presented to the experimental group during the night. There was no significant difference between the two groups, but the experimental group showed significant improvement over its first average score.

Although no highly positive findings were obtained, Elliott's results seem to indicate that learning may take place during sleep, and that more experimentation is necessary. In view of the difference between his findings and the present results, it is suggested that the classical excess of savings in the learning of more

[1] Editor's note: The conclusiveness of this study suffers somewhat from the failure to *observe* the *S*s during sleep. Nevertheless, the importance of the problem, and the persuasiveness of the findings, have dictated acceptance and publication.

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notified for the second portion of the experiment and was requested not to discuss the pretest with anyone.

The *S*s were then divided into three matched groups. In each group there were three *S*s who took four trials to reach the criterion, three *S*s who took five trials, and four *S*s who took six trials. Later in the experiment some of the above were disqualified because they had to break off the experiment, because they woke up during the sleep presentation, or because they reported bad sleep habits. These were replaced by *S*s who had pretest scores identical with those of the disqualified *S*s.

Sleep procedure.—Contact for the sleep procedure was usually made within three or four days of the pretest. At this time the *S*s were instructed to abstain from coffee, alcohol, and any unusual excitement on the day preceding this night. All *S*s used reported that they were usually asleep an hour after retiring.

The *E* arrived at the *S*'s home between 8:00 and 10:30 P.M. to set up the machine. At first, this was placed close to the bed; later, this position was changed to a more distant one when it was discovered that many *S*s awoke because of the noise and vibrations (they said) of the machine during the playback, even though to the listener in daytime such noise was inaudible.

Gibbs and Gibbs (3) suggest that maximum depth of sleep is attained at about 2:30 to 3:00 A.M. if *S* retires at 11:30 P.M. However, it has been pointed out (6) that this is not true for all sleepers. Kleitman's work (7) indicates a series of fluctuations of depth of sleep during the night. In any case, the machine was set to run for the half-hour between 2:30 and 3:00 A.M.

The *S*s were reminded to be in bed by 11:30 and to refrain from all forms of reading, writing, and conversation upon awakening.

Each group was given only one night's exposure to the apparatus for the test run. The facilitation and interference groups both were presented during sleep with 15 repetitions of the appropriate list of Chinese words. The list with correct translations, used with the facilitation group, was as follows: tien^2-field; mu^4-eye; li^3-strength; ta^4-great; ming^2-bright; shao^3-few; lin^2-grove; siao^3-small; jia^1-home; sheng^1-life; tu^4-ground; ko^3-may; dao^4-road; fen^1-knife; lo^4-fall; rih^4-day; jun^1-sir; dung^1-east; hao^3-good; yen^2-talk; ru^2-like; süe^2-snow; wu^3-five; lai^2-come; je^4-this. The control group heard Strauss waltzes for a like period. Recorded time of each tape presentation was a little over 29 min.

The interference group heard the Chinese in proper order but with mismatched English "equivalents." The list was as follows: tien^2-five; mu^4-east; li^3-road; ta^4-may; ming^2-come; shao^3-life; lin^2-this; siao^3-talk; jia^1-great; sheng^1-few; tu^4-bright; ko^3-strength; dao^4-field; fen^1-eye; lo^4-grove; rih^4-snow; jun^1-fall; dung^1-knife; hao^3-ground; yen^2-day; ru^2-sir; süe^2-good; wu^3-small; lai^2-home; je^4-like.

Posttest procedure.—The following morning *E* arrived at *S*'s home between 8:00 and 10:30 A.M. depending on *S*'s convenience. An attempt was made to come as close as possible to the normal waking hour to prevent the effects of retroactive inhibition from becoming too active. Each *S* was asked if he had heard the machine go on during the night, if he had had any dreams, and if he felt more fatigued than on most other mornings. The posttest record was placed on the machine and *S* was given the same instructions that were given him during the pretest situation. Recording and scoring were done in a similar manner. After the criterion of one perfect trial had been reached, *S* was requested to describe the method he used in learning the list. After this, he was thanked for his cooperation and given an admonition about not discussing the experiment with anyone.

An effort was made at the beginning of the experiment to mislead the *S*s as to the purpose of the experiment by telling them that their spontaneous vocalizations during sleep would be recorded. Most refused to be misled, however, and it was necessary to inform the *S*s as to the nature of the experiment.

Results and Discussion

The three groups chosen from scores on the pretest all had means of 5.1 trials and *SD*'s of .83 trials to learn the list to one correct repetition. The results for each *S* in the posttest, following sleep stimulation, are shown in Table 1.

The mean difference between each of the groups and each of the others was significant at better than the 1% level of confidence whether differences were taken as correlated or uncorrelated ($df = 18$, t for Control vs. Facilitation Groups in 4.37, t for Control vs. Interference Groups is 7.08, and t for Facilitation vs. Interference Groups is 10.37). Furthermore, it is clear from the scores of the individual *S*s that these group differ-

TABLE 1

TRIALS TO LEARN POSTTEST MATERIAL AFTER EXPOSURE TO SLEEP STIMULI

Subject	Pretest Trials*	Posttest Trials		
		Control Group	Facilitation Group	Interference Group
1	4	8	6	12
2	4	8	7	10
3	4	6	5	11
4	5	7	6	9
5	5	9	4	12
6	5	9	5	11
7	6	8	8	10
8	6	7	5	11
9	6	7	5	12
10	6	8	5	13
Mean	5.1	7.7	5.6	11.1
σ_m	.28	.30	.37	.38

* These trials were used as the basis for matching the ten *Ss* in each group. The correlations between the pretest trials and posttest trials are .04, −.06, and .20 for the control, facilitation, and interference groups, respectively.

ences are the result of factors which almost without exception affect each individual in the same direction.

The experimental situation did not allow verification by *E* of the condition of actual sleep during the night, as was the case in Elliott's study (1). However, the *Ss* were questioned about this, and all those who reported hearing the machine or waking up were eliminated as *Ss*. These numbered ten. If any *Ss* in the group of 30 actually did wake up without reporting it, then the number was probably distributed about equally throughout the groups. Moreover, since all *Ss* (with the exception of matched *Ss* No. 7 in the Control and Facilitation Groups) show effects in the expected directions, it is clear that the results cannot be explained on the basis of a few *Ss* in each group who awakened but failed to report doing so.

It is of interest that all *Ss* reported learning the list by associating the Chinese word with the English, rather than by learning the English words in sequence, a possibility in this type of learning situation when the order of presentation of pairs is not varied from trial to trial.

An interesting addendum, supporting the demonstration of influence of Chinese syllable presentation during sleep, is that dreams relating to the stimuli appeared. One *S* dreamed of a street scene in China; another of the pretesting situation; and a third that her instructor stood over her reading a long list of Chinese syllables. (The instructor was the one who actually did read to the tape recorder.) This phenomenon has been amply demonstrated (2). The further implications of these findings are enormous and obvious.

SUMMARY AND CONCLUSIONS

Out of 62 *Ss* given a pretest on learning the English equivalents of 15 Chinese words, 30 *Ss* were selected on the basis of equivalent scores and perfectly matched into three groups. A facilitation group (A) heard a different list of 25 words and correct equivalents repeated 15 times during sleep; a control group (C) heard music for an equal period during sleep; and an interference group (B) heard the 25 words and incorrect equivalents made up by mismatching the correct ones. The next morning the average number of trials taken to learn the list presented to the A group was as follows: facilitation group, 5.6; control group, 7.7; and interference group, 11.1. These differed significantly from one another.

It can be concluded that learning can occur during sleep and can be detected by the saving method.

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